EXHIBIT E

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

HONEYWELL INTERNATIONAL INC.; and HONEYWELL INTELLECTUAL PROPERTIES INC.; Plaintiffs,	Civil Action No. 04-1337 (***) Civil Action No. 04-1338 (***) Civil Action No. 04-1536 (***) Civil Action No. 05-874 (***) (Consolidated)
v.	
APPLE COMPUTER, INC., et al. Defendants.	

EXPERT REPORT OF ROBERT D. SMITH-GILLESPIE

CONCERNING U.S. PATENT NO. 5,280,371

CONTAINS HIGHLY CONFIDENTIAL INFORMATION

SUBJECT TO PROTECTIVE ORDER - OUTSIDE ATTORNEY'S EYES ONLY

E. Optical micro-structures and the directional diffuser

(17) Micro-structured optical elements are composed of a series of structured surfaces. MSOEs may have straight or curved profiles with constant or variable spacing with pitches from microns to millimeters and may be circular, linear or random. See Figure 7 for examples.

> **lens** *noun*: a piece of transparent material (as glass) that has two opposite regular surfaces either both curved or one curved and the other plane and that is used either singly or combined in an optical instrument for forming an image by focusing rays of light. (Merriam-Webster On-line© 2006-2007)
>
> **lenslet** *noun:* A lenslet is literally a small lens. The fact that distinguishes it from a small lens is that it is part of a lenslet array. A lenslet array consists of a set of lenslets in the same plane. Each one normally has the same focal length. (www.wikipedia.com)
>
> **lenticular** *adjective:* 1: having the shape of a double-convex lens; 2: of or relating to a lens; 3: provided with or utilizing lenticules <a lenticular screen> (Merriam-Webster On-line© 2006-2007) Also known as linear lens arrays or cylindrical lens arrays, lenticulars have linear structures, where every groove is the same and each groove has a small radius of curvature, thus creating multiple line images. These components can also be used as diffusers or to spread light in a single direction. (Reflexite – www.display-optics.com)
>
> **lenticule** *noun:* 1: any of the minute lenses on the base side of a film used in stereoscopic or color photography 2: any of the tiny corrugations or grooves molded or embossed into the surface of a projection screen (Merriam-Webster On-line© 2006-2007)
>
> **Fresnel lens** *noun:* Etymology: Augustin J. Fresnel: a lens that has a surface consisting of a concentric series of simple lens sections so that a thin lens with a short focal length and large diameter is possible and that is used especially for spotlights. (Merriam-Webster On-line© 2006-2007) A Fresnel lens has a micro-structured surface which consists of a series of grooves with changing slope angles as the distance from the optical axis increases. A Fresnel prism has a linear structure with constant prism and draft angles. It deflects collimated light with a constant deflection angle.

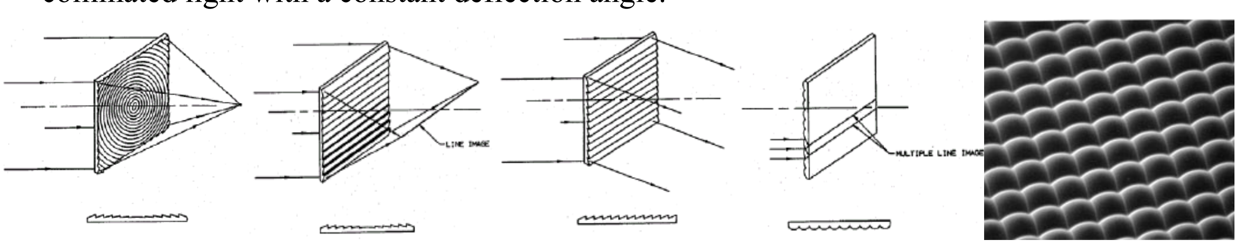

Figure 6. Optical micro-structured lens arrays. L-R: Spherical, cylindrical, prismatic Fresnel lens; linear cylindrical lens array (also called lenticular array), Moth eye lens array. (www.reflexite.com)

> "first and second lens arrays, each having a plurality of individual lenslets . . . for providing a predetermined variation with viewing angle of light transmission from said light source through said lens arrays and said liquid crystal panel"
>
> is properly interpreted to mean:
>
> two lens arrays each consisting of a member separate from the light source and having a plurality of lenslets. The lens arrays are arranged such that the lenslets on the first and second lens arrays:
>
> a) face toward the liquid crystal panel;
>
> b) are parallel to each other, and parallel to the horizontal axis of the liquid crystal panel (aside from any "slight misalignment"); and
>
> c) have different pitches from each other and from the liquid crystal panel;
>
> for providing a variation of light transmission with vertical viewing angle.

(91) **Between said light source and liquid crystal panel**. Claim 3 requires the lens arrays to be located "between said light source and said liquid crystal panel." The '371 patent states that "an air gap must be present at the interface of the lambertian diffuser and the lens array" [Col. 3, lines 55-56]. It is my opinion that the '371 patent here teaches that the lens array and the lambertian diffuser must be optically separated by an air gap. For these reasons, it is my opinion that the phrase "between said light source and said liquid crystal display" is properly interpreted to mean "positioned between the light source and the liquid crystal panel, with an air gap at the interface of the light source and the one of the lens arrays closest to the light source."

(92) **Rotated …to provide a slight misalignment.** Claim 3 finally requires "at least one of the lens arrays is rotated about an axis perpendicular to the liquid crystal panel in order to provide a slight misalignment between said lenslets and said liquid crystal panel." There is only one sentence in the specification that addresses rotation of the lens arrays. That sentence is found in the following paragraph:

EXHIBIT F

US005161041A

United States Patent [19]

Abileah et al.

[11] Patent Number: 5,161,041

[45] Date of Patent: Nov. 3, 1992

[54] LIGHTING ASSEMBLY FOR A BACKLIT ELECTRONIC DISPLAY INCLUDING AN INTEGRAL IMAGE SPLITTING AND COLLIMATING MEANS

[75] Inventors: **Adiel Abileah**, Farmington Hills; **Charles Sherman**, Royal Oak; **Robert M. Cammarata**, Sterling Heights, all of Mich.

[73] Assignee: **OIS Optical Imaging Systems, Inc.**, Troy, Mich.

[21] Appl. No.: **514,737**

[22] Filed: **Apr. 26, 1990**

[51] Int. Cl.[5] G02F 1/1335
[52] U.S. Cl. 359/40; 359/49
[58] Field of Search 350/334, 345; 359/40, 359/49

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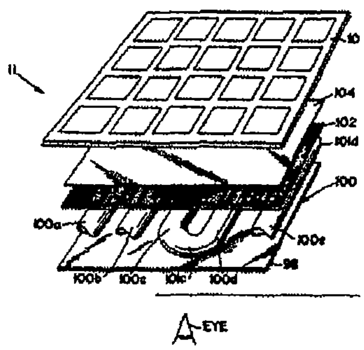
Primary Examiner—Stanley D. Miller
Assistant Examiner—Anita Pellman Gross
Attorney, Agent, or Firm—Myers, Liniak & Berenato

[57] **ABSTRACT**

An improved lighting assembly for a backlit electronic display includes an integrally formed image splitting-/collimating lens for effectively enlarging the area illuminated by any one or part of one of the lamps of the source of backlighting. Through the use of the improved optical assembly described herein, there is provided a backlit electronic display characterized by fewer lamps, reduced heating, and vastly improved intensity of illumination per unit area in a lower profile package.

22 Claims, 4 Drawing Sheets



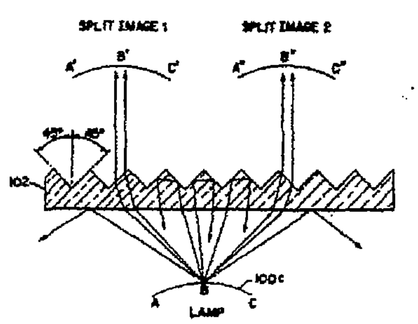


Fig.1

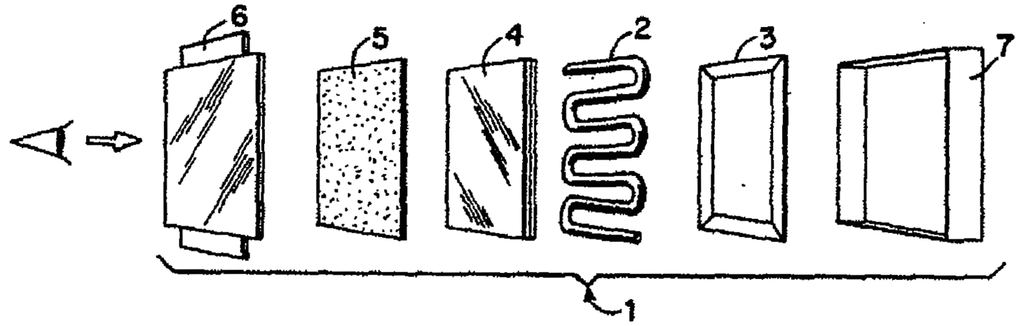


Fig.2A

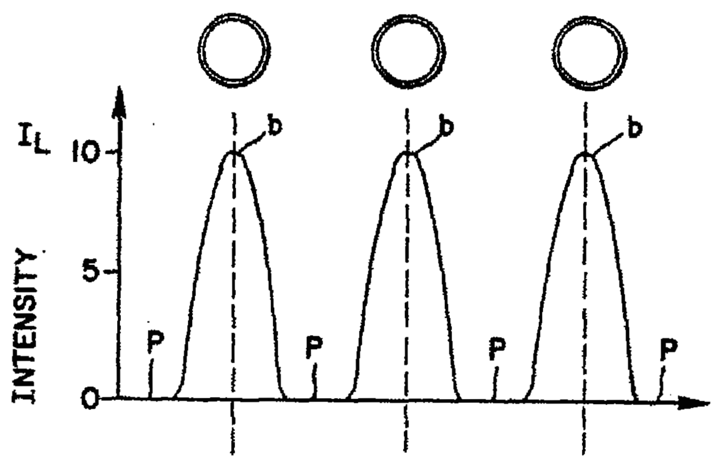


Fig.2B

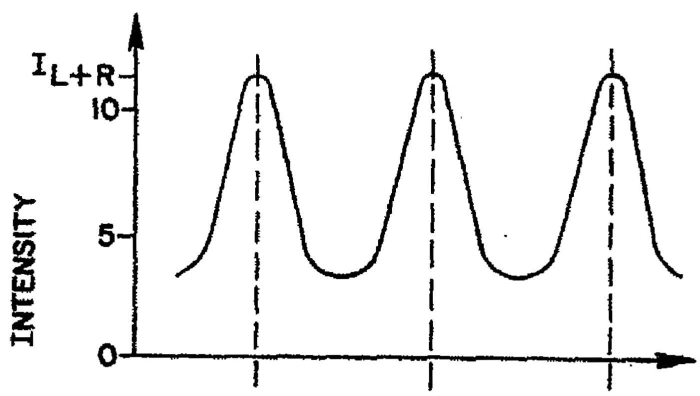


Fig.2C

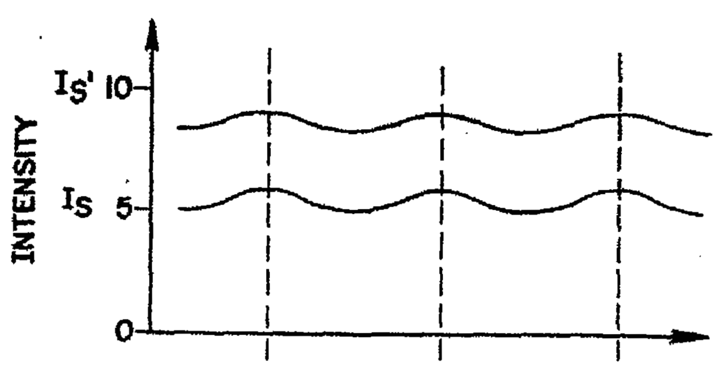


Fig.3

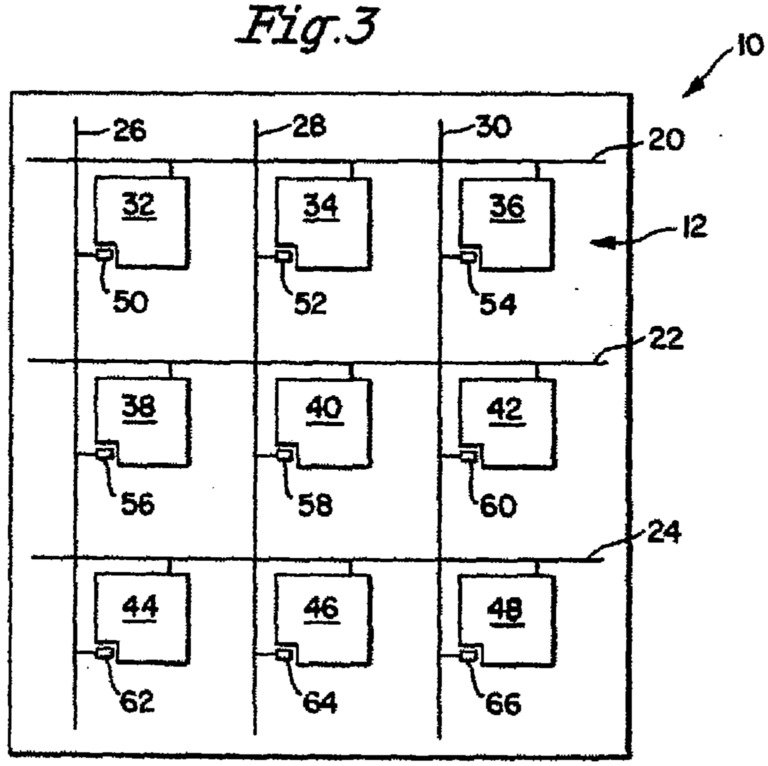


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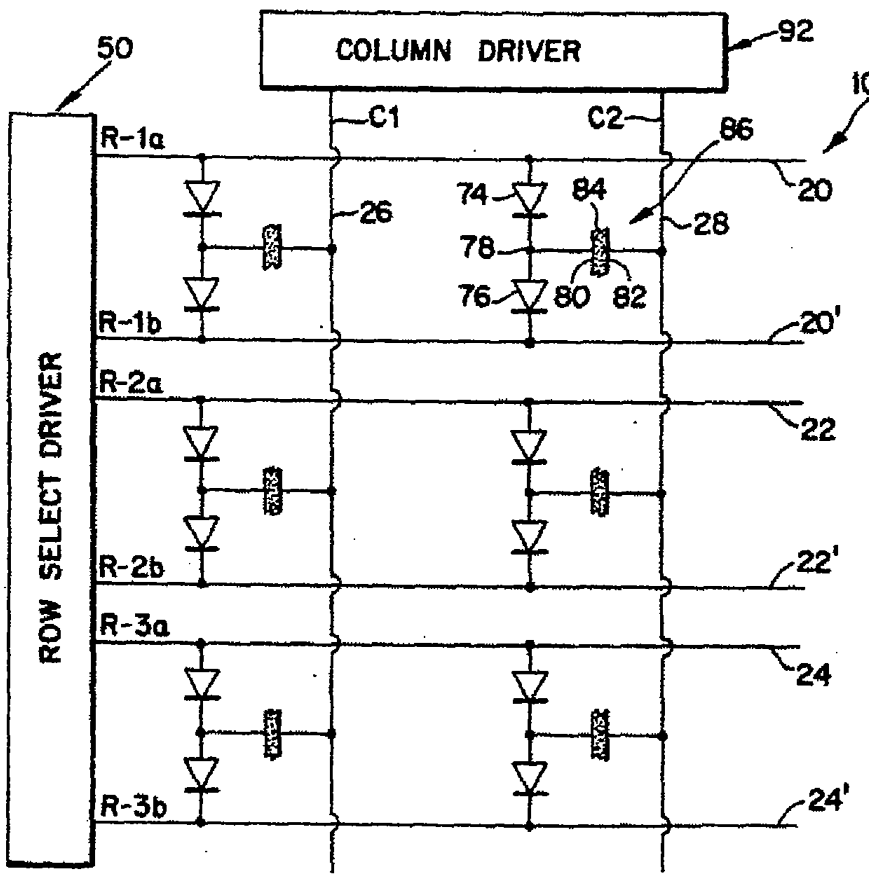
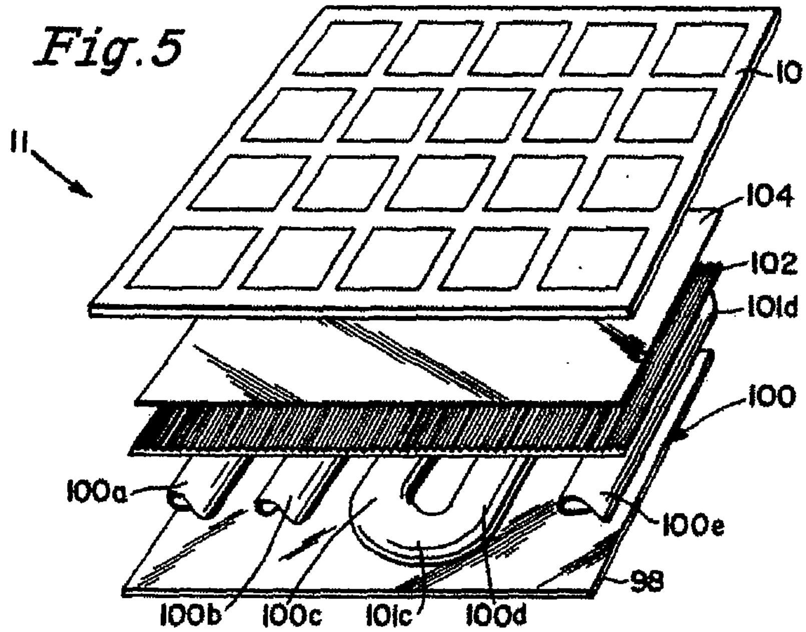
Fig.4



COLUMN DRIVER
92
50
10'
C1
C2
86
R-1a
20
74
84
26
28
78
76
80
82
R-1b
20'
R-2a
22
R-2b
22'
R-3a
24
ROW SELECT DRIVER
R-3b
24'

Fig. 5



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100a
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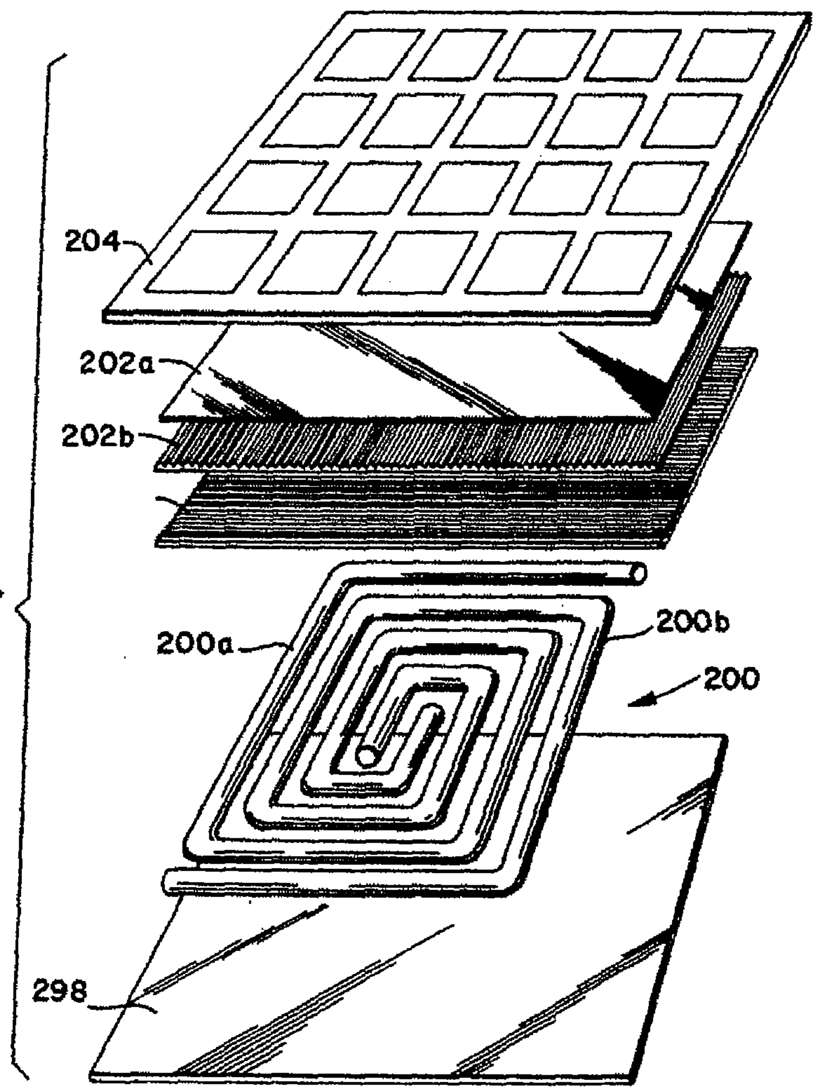
101c
100d

Fig. 6



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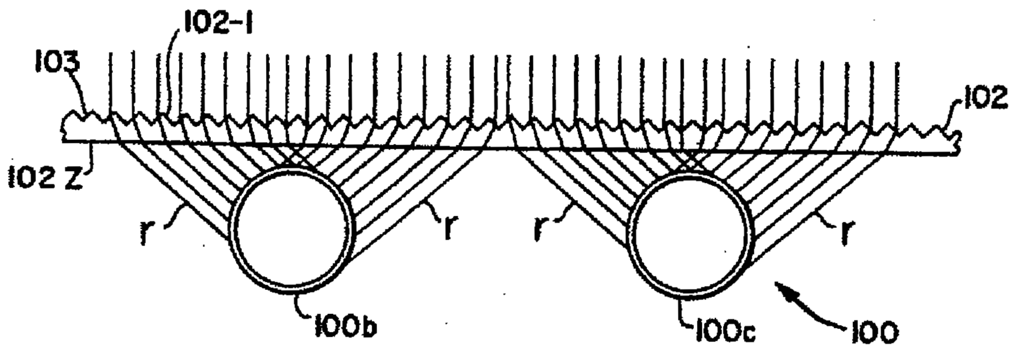
202b
200a
200b
200
298

Fig. 7


102-1
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102 Z
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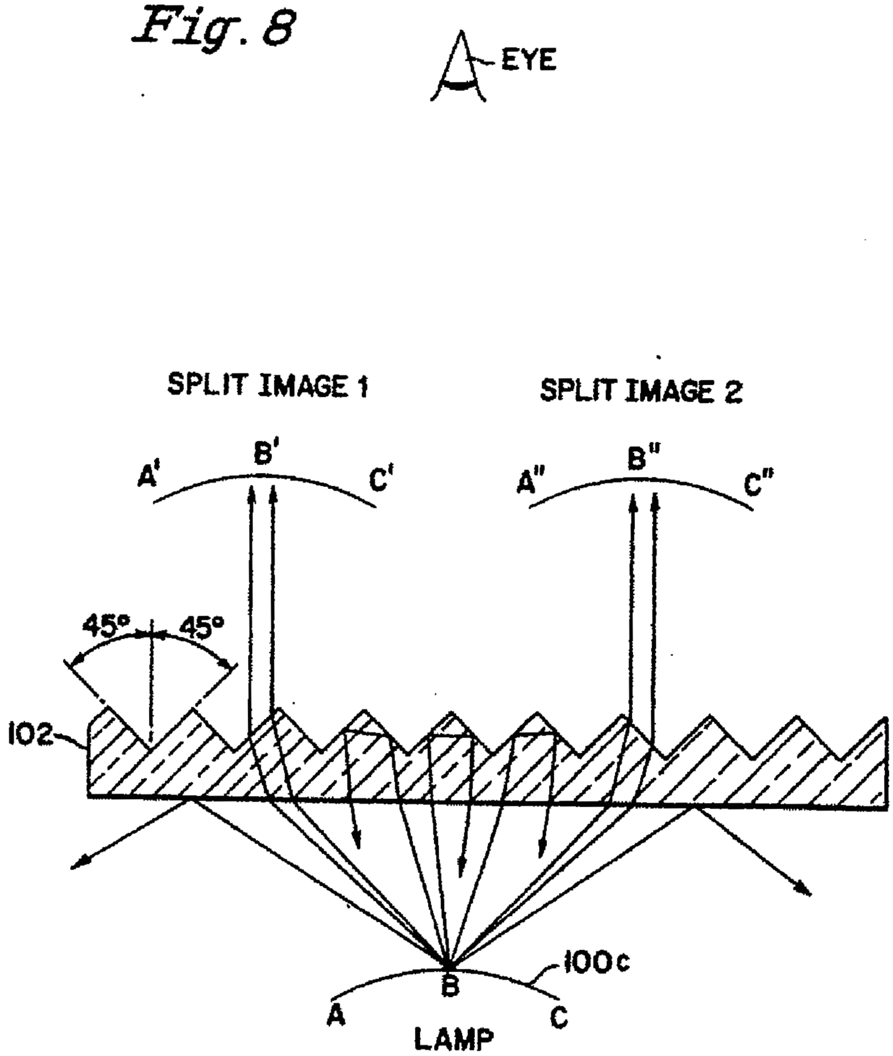
Fig. 8


EYE
SPLIT IMAGE 1
SPLIT IMAGE 2
A'
B'
C'
A"
B"
C"
45°
45°
102
100c
A
B
C
LAMP

LIGHTING ASSEMBLY FOR A BACKLIT ELECTRONIC DISPLAY INCLUDING AN INTEGRAL IMAGE SPLITTING AND COLLIMATING MEANS

FIELD OF THE INVENTION

The instant invention relates generally to the field of electronic two dimensional liquid crystal displays, which displays are adapted to provide either still or video images to a remotely positioned viewing audience. The instant invention more particularly relates to the field of backlit liquid crystal displays particularly adapted for military and avionic applications and which are specially designed to present a bright, uniform distribution of light to said viewing audience in a low profile, i.e., minimum depth assembly.

The unique and improved backlit module disclosed in the instant specification finds an important use in full color active matrix liquid crystal displays, particularly those adapted for military and avionic use. This module achieves about one order of magnitude improvement in a figure of merit (FOM) described by the function: FOM =(lamp power/viewing angle) * (backlight thickness/ lamp life), which improvement has been achieved by decreasing the needed lamp power thereby resulting in an increase in lamp life. Additionally, the lighting arrangement set forth in the instant invention features a redundant configuration, intense illumination, uniform illumination, thermal control of the lamps and thin packaging.

BACKGROUND OF THE INVENTION

In recent years, a considerable amount of research has been conducted in an effort to develop a low profile (thin), full color, electronic display system which does not rely upon conventional cathode ray tube technology. In systems such as television receivers, computer monitors, avionic displays, aerospace displays, and other military-related displays, the elimination of cathode ray tube technology is desirable for several reasons, which reasons will be detailed in the following paragraphs.

More particularly, cathode ray tubes are typically characterized by extremely large depth dimensions and thus occupy a considerable amount of floor or counter space. As a matter of fact, the depth dimension may equal the length and width dimensions of the viewing screen. Also, because cathode ray tubes require an elongated neck portion to provide for the acceleration of an electron beam from the electron gun to the faceplate of the cathode ray tube, they are quite irregular in shape. Additionally, since cathode ray tubes are fabricated from relatively thick glass, they are inordinately heavy, extremely fragile and readily breakable. Finally, cathode ray tubes require a relatively high voltage power supply in order to sufficiently accelerate the electron beam and thus sustain the displayed image.

The reader can readily appreciate the fact that all of the foregoing problems experienced with or shortcomings of cathode ray tubes are exacerbated as the size of the viewing screen increases. Since the current trend, and in fact consumer demand, is toward larger screens; weight, breakability, placement, etc. represent significant commercial considerations. Accordingly, it should be apparent that cathode ray tubes are and will continue

to be inappropriate for those applications in which weight, fragility and portability are important factors.

One system which can eliminate all of the aforementioned shortcomings of the present day cathode ray tube is the flat panel liquid crystal display in which a matrix array of liquid crystal picture elements or pixels are arranged in a plurality of rows and columns. Liquid crystal displays may typically be either reflective or transmissive. A reflective display is one which depends upon ambient light conditions in order to be viewed, i.e., light from the surrounding environment incident upon the side of the display facing the viewer is reflected back to the viewer. Differences in the orientation of the liquid crystal material within each liquid crystal pixel cause those pixels to appear either darkened or transparent. In this manner, a pattern of information is defined by the two dimensional matrix array of darkened (or transparent) pixels. However, and as should by now be apparent, reflective liquid crystal displays cannot be used in a dark or low light environment since there is no light available for reflection off the viewing surface of the display.

Conversely, transmissive liquid crystal displays require the use of illuminating means such as a lamp array operatively disposed on the side of the matrix array of picture elements opposite the viewer. This illumination means or backlight may further include a backreflector adapted to efficiently redirect any stray illumination towards the matrix array of rows and columns of picture elements, thus ensuring that the displayed image is as bright as possible (given the lighting capabilities and characteristics of the backlighting scheme being employed). The instant invention is specifically directed to the field of backlit, high resolution liquid crystal electronic displays.

The characteristics of the backlighting scheme are very important to both the quality of the image displayed by the matrix array of picture elements of the liquid crystal display and the profile, i.e., the thickness dimension, of that liquid crystal display. Accordingly, a great deal of the aforementioned research in the field of said flat panel electronic displays has been dedicated to the design and fabrication of backlighting systems which optimize certain viewing and structural parameters of those flat panel displays. Characteristics which are acknowledged by experts as the most important in the design of optimized backlighting assemblies include: 1) uniformity across the large surface areas illuminated by the light provided by the backlight, i.e., the intensity of the light must be substantially the same at each pixel of the large area liquid crystal display; 2) high brightness illumination provided by the backlight thus yielding a sharp, readily readable image to a remotely positioned viewing audience; 3) a low profile so that a flat panel liquid crystal display is substantially flat and can be operatively disposed for viewing without occupying an undue amount of available space; 4) the overall design of the backlight which takes into consideration the number, configuration, and redundancy of lamps; 5) the heat effect caused by the number, configuration, redundancy and type of the lamps; and 6) the total power consumed by the lighting scheme which represents an extremely important consideration in hand held (portable) television units.

A number of different backlight configurations, all of which included a plurality of discrete optical components disposed between the plane of the source of backlit radiation and the plane of the matrix array of liquid

crystal pixels, have been designed in an effort to maximize each of the desirable characteristics recited hereinabove. For example, those of ordinary skill in the art of liquid crystal display backlighting have attempted to use light diffusers in an effort to achieve a more uniform distribution of projected light across the entire viewing surface of the liquid crystal display. This technique, while useful for improving the uniformity of projected light, deleteriously affected the intensity of that projected light resulting in light appearing soft or washed-out. Thus, additional lamps were required when such light diffusers were employed, resulting in an increased heating effect upon the display. Further, due to the fact that such light diffusers were, of necessity, positioned an operative distance from both the source of backlighting as well as from the matrix array of liquid crystal pixels, the depth dimension or profile of the electronic, flat panel display was significantly increased.

A second technique employed to enhance the quality of the backlight (and hence the quality of the displayed image) is to operatively dispose a light collimating lens, such as a fresnel lens, between the source of the backlight and the matrix array of liquid crystal picture elements. This design expedient has the effect of producing an intense, sharp image from a minimal number of lamps, while simultaneously providing a high degree of uniformity of projected radiation across the entire viewing surface of even large area displays. However, due to the nature of collimated light, the viewing angle of a display equipped with such a light collimating lens is limited. Indeed, viewing of the displayed image is impossible from any angle other than directly straight-on. Accordingly, a backlit display which employs only a light collimator without a mechanism for increasing the viewing angle has limited commercial applicability, and is wholly inappropriate for the gigantic markets related to television and computer monitors. Additionally, collimating means, such as fresnel lenses, are characterized by an operative focal length. (The focal length is that distance from the light source at which said lens must be disposed in order to properly collimate light emanating from said light source.) Thus, the light collimator has the undesirable effect o increasing the profile of the liquid crystal display. Also, backreflectors are inappropriate for use with light collimating. This is because light reflected from the backreflector does not originate from a position which is at the focal length of the collimating lens. Hence, light reflected from said backreflector will not be collimated. This results in localized bright spots on the surface of large area displays, degrading the quality of the displayed image.

In a effort to achieve the advantages of both light collimation and light diffusion, routineers in the backlit, flat panel liquid crystal display art have attempted to incorporate both a discrete light diffuser and a discrete light collimator into the same backlit liquid crystal display. Optically speaking, the results have been satisfactory only to the extent that the quality of the displayed image is relatively sharp, intense and uniform; while said image is visible over a relatively wide viewing angle. However, in order to maximize the optical effect of utilizing the diffuser-collimator combination, it was necessary to operatively space the collimator from the source of backlighting radiation, and then to space the diffuser from both the plane of the collimator and the plane of the matrix array of liquid crystal pixels. The result was a substantial increase in the profile, i.e., the depth dimension of the liquid crystal display. Indeed, in typical liquid low profile crystal display systems which include both a light collimator and a light diffuser, the distance from the light source to the diffuser is approximately 17 millimeters. It can thus be seen that by including both diffusing and collimating optical components, the profile of a typical flat panel liquid crystal display is significantly increased, thus eliminating one of the principle advantages of liquid crystal display systems; i.e., compactness. One method of reducing the depth profile and providing the foredescribed improved optical effect is disclosed in copending United States patent application No. 473,039, filed Jan. 31, 1990, assigned to the assignees of the instant application, the disclosure of which is incorporated herein by reference.

While the commonly assigned and copending application improved the profile and optical characteristics of prior art electronic displays having a given figure of merit for intensity of illumination per unit area, that application did not deal with improvements in the lighting efficiencies so as to reduce the number of lamps, the thermal effects of those lamps and the power consumption of those lamps. Accordingly, there still exists a need in the flat panel liquid crystal display art for an improved lighting/optical arrangement which provides a bright, uniform image of high contrast and capable of being viewed over a wide viewing angle, while maintaining a narrow profile and minimizing power consumption and thermal inconveniences.

BRIEF SUMMARY OF THE INVENTION

There is disclosed herein an improved backlit electronic display and specifically a liquid crystal display adapted to provide an image to one or more remotely positioned observers. The improved liquid crystal display is defined by a matrix array of rows and columns of liquid crystal picture elements spacedly disposed from one side of a light source, and means for collimating light operatively disposed between said light source and said rows and columns of liquid crystal picture elements. The improvement in the display of the instant invention residing in the incorporation therein of an image splitting means adapted to enlarge the area effectively illuminated by said light source, said image splitting means and said collimating means forming an integral image splitting/collimating lens. In this manner, a bright, uniform distribution of light is provided in a low profile display.

The display preferably includes a backreflector which is operatively disposed on the side of the light source opposite the image splitting/collimating lens. The display preferably further includes means for diffusing light emanating from the light source, the light diffusing means operatively disposed between said image splitting/collimating lens and said rows and columns of liquid crystal picture elements. In one preferred embodiment, the light source is configured as a single, elongated, serpentine, tubular lamp arranged in a series of elongated parallel lobes. In a second, equally preferred embodiment, the light source may be configured as a plurality of discrete tubular lamps, said lamps defining a given lighting configuration. Regardless of whether the light source defines a lighting configuration formed of a single elongated tubular lamp or a plurality of discrete lamps, said image splitting/collimating lens will comprise a substantially planar thin film sheet having multi-faceted prisms formed on one surface thereof.

The prisms formed on said image splitting/collimating lens are operatively disposed so as to provide an image splitting effect in one dimension of the sheet. In alternative embodiments, the image splitting/collimating film may either be laminated onto a substrate or actually formed thereupon. The substrate is thin and transparent and formed of glass, a ceramic or a synthetic plastic resin. Regardless of the material from which the substrate is fabricated, the direction in which the image splitting/collimating lens is adapted to split radiation corresponds to the longitudinal dimension of the light source. More specifically, rays of light emanating from said light source are refracted on each side of said image splitting/collimating lens to provide two similar images thereof. Of course, the distance between the two similar images is controlled by the operative spacing of s id image splitting/collimating means from said light source. In a preferred embodiment, the image splitting/collimating means is operatively spaced from said light source so that said two similar images are operatively disposed immediately adjacent to one another.

It must be emphasized that the improved backlighting arrangement of the instant invention will operate with equal effectiveness in passive displays as well as in active matrix electronic displays. In such active matrix liquid crystal displays, each picture element will include a pair of electrodes having liquid crystal material operatively disposed therebetween and at least one threshold device. The threshold devices may either be diodes or field effect transistors. Where two threshold devices are employed, they are electrically coupled together at a common node in non-opposing series relationship. The threshold devices preferably comprise diodes formed from deposited thin film layers of amorphous silicon alloy material of p-i-n construction.

In one final embodiment of the invention, the light source can be defined by a plurality of lamps operatively disposed in two orthogonal directions. In such an embodiment, it is necessary to employ a set of two image splitting/collimating lenses. One of those image splitting/collimating lenses will be operatively disposed on top of the second and offset by 90 degrees therefrom. This combination of image splitting, light collimation and light diffusion provides for a thin and efficient assembly which yields a uniform distribution of light over the large surface areas of the display.

These and other objects and advantages of the instant invention will become apparent to the reader from a perusal of the Detailed Description Of The Invention, the Drawings and the claims, all of which follow immediately hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded perspective view illustrating the component elements typically present in a liquid crystal display adapted for use in military and avionic applications;

FIG. 2A is a graph of light intensity distribution in which the intensity of illumination is plotted o the ordinate and the horizontal position across the viewing surface of an electronic display of the type illustrated in FIG. 1 is plotted on the abscissa;

FIG. 2B is a graph of light intensity distribution in which the intensity of illumination is plotted on the ordinate and the horizontal position across the viewing surface of an electronic display of the type illustrated in FIG. 1, including a reflector, is plotted on the abscissa;

FIG. 2C is a graph of light intensity distribution in which the intensity of illumination is plotted on the ordinate and the horizontal position across the viewing surface of an electronic display is plotted on the abscissa, and illustrating in curve I a conventional backlighting arrangement and in curve I' the improved backlighting arrangement of the instant invention;

FIG. 3 is a stylistic front elevational view of the matrix array of rows and columns of liquid crystal picture elements of the active matrix embodiment of the electronic display o the instant invention schematically illustrating the manner in which the threshold switching elements are operatively disposed between the address lines and one of the picture element electrodes;

FIG. 4 is an equivalent circuit diagram of the active matrix embodiment of the array of FIG. 3, illustrating the relationship between the liquid crystal picture elements and the anode-to-cathode connected diodes by which individual ones of the picture elements schematically depicted in FIG. 3 are addressed;

FIG. 5 is a fragmentary perspective view illustrating the relative disposition of one preferred embodiment of the image splitting/collimating lens array of the instant invention relative to a first embodiment of an axially aligned array of tubular lamps;

FIG. 6 is a fragmentary perspective view illustrating the relative disposition of the image splitting/collimating lens array of the instant invention relative to a second embodiment of a square helical array of tubular lamps; and

FIG. 7 is a cross-sectional view of FIG. 5 and illustrating the manner in which rays of light emanating from the axially aligned lighting configuration of FIG. 5 are split and collimated by the optical media of the image splitting/collimating lens array of the instant invention.

FIG. 8 is a partial cross-sectional schematic view of FIG. 7 illustrating the manner in which the rays of light emanating from the light source are refracted on each side of the integral image splitting/collimating lens to provide two similar images thereof.

DETAILED DESCRIPTION OF THE INVENTION

Disclosed as part of the instant invention is an improved backlighting assembly for an electronic display, such as a liquid crystal display and most specifically, by way of example and not by way of limitation, to an active matrix liquid crystal display for military and avionic applications. Active matrix liquid crystal displays, which operate in full color and in the transmissive mode, represent the primary choice of flat panel technologies for avionic and military applications because of their sunlight readability, high resolution, color and gray scale capability, low power consumption and thin profile. It is to be specifically noted that while an active matrix liquid crystal display will be described in detail hereinafter as a preferred embodiment, the instant invention can be used with equal advantage in any type of backlit electronic display known to routineers in the art. Therefore, the improved backlighting assembly described herein is adapted to enhance lighting parameters such as brightness, redundancy of lamps, low heat effects, while simultaneously providing a low profile to the overall depth dimension of the display structure. With the foregoing objectives clearly in mind, the improved assembly will be described in greater detail in the following paragraphs.

In order for electronic displays to gain increased acceptance in military and avionic applications, the backlighting of flat panel displays, and particularly active matrix liquid crystal displays, must be improved in light efficiency and reliability. In order for a full color liquid crystal display to possess acceptable contrast under high ambient lighting conditions, the backlighting arrangement must be bright. While current backlighting systems have the requisite light output, they still require high power (on the order of 2.4 watts/square inch) and a depth dimension of about two inches. In contrast thereto, the backlight assembly of the instant invention consumes only about 1.2 watts/square inch of power with a depth dimension of only about one inch. In addition, this design increases lamp life, a critical parameter in the design and successful marketing of electronic displays, to approximately 8,000 hours or more from the typical values of about 4,000 hours exhibited by prior art lighting arrangements.

Liquid crystal displays operate as light modulators and do not emit light. Therefore, liquid crystal displays rely upon ambient illumination or backlighting to provide the light necessary for reading. Active matrix liquid crystal displays use a twisted nematic liquid crystal material and two polarizers as the optical components in the modulating mechanism. These materials, together with the color filters, result in a color display panel which can only transmit about 5% of radiation incident thereupon. Therefore, a bright backlight is necessary in order for full color displays to be clearly readable in bright ambient environments.

All backlighting assemblies designed for active matrix liquid crystal display applications have the same basic components. More specifically, each backlighting assembly includes a light source, an optical system comprising one or more lenses for altering the nature of the light emanating from said light source, and light source control electronics (ballast). An exploded perspective view of a fluorescent lamp-based backlight assembly is illustrated in FIG. 1. The backlight assembly depicted therein is represented generally by the reference numeral and, as is typical in the industry, employs a tubular fluorescent lamp 2 as the light source. Of course, the lamp 2 may be arranged in any one of a plurality of well known configurations: it may be serpentine as shown in FIG. 1, alternatively the lamp may be "U-Shaped", or straight.

Returning now to FIG. 1, the typical backlight system further includes a backreflector 3, a lens element 4, and a diffuser 5. Of course, disposed in front of the backlight assembly 1 is a display element comprising a plurality of rows and columns of liquid crystal picture elements adapted to be illuminated by said backlight assembly. The purpose of the backreflector 3 is to redirect light which is not initially directed towards the display element so that the maximum amount of light available from a given light source is directed towards the display 6.

Generally speaking, the optical element 4 is provided to alter or enhance the quality of the light emanating from the light source. While the optical element is an important, indeed necessary, component of the backlight system, it is often the primary cause of increased profile (i.e., increased thickness) in a liquid crystal display system. This is due to the fact that in order to achieve the desired optical effect, it is often necessary to operatively space the plurality of lenses which make up the optical element a preselected distance from one another. For example, a collimating lens such as a Fresnel lens is characterized by a focal length which defines the operative spacing from the light source necessary for the lens to effectively collimate the light. This spacing, along with the operative spacing required by, for example a diffuser significantly increases the profile of the backlight assembly.

It is to the end of reducing the profile of the liquid crystal display system that the instant invention is directed. This is accomplished by incorporating two necessary optical components, an image splitting lens and a collimating lens into a single, integral image splitting-/collimating lens. More particularly, the instant invention includes an image splitting lens for effectively doubling the area which the light source can uniformly and effectively illuminate. The image splitting lens is however further adapted to collimate the light emanating from the lamp 2 for uniform distribution onto the back of the matrix forming the liquid crystal display 6. There are several ways to obtain light collimation, such as, for example, through the use of various combinations of parabolic shaped reflectors and lens elements. However, the image splitting means of the instant invention is adapted to collimate light passing therethrough due to the presence of multi-faceted prisms formed on the surface thereof. Specifically, engineered facets of close tolerances will not only achieve the desired optical effect of splitting the image of the light source, but will also collimate each image.

The instant inventors have found that a material ideally suited for use as an image splitting/collimating lens is Optical Lighting Film (registered Trademark of 3M Scotch) which is subsequently laminated onto a transparent substrate such as glass, other ceramic or a synthetic plastic resin. By employing an integrally formed image splitting/collimating lens it is thus possible to achieve two desired optical effects with a decrease in the profile of the display as compared to other non-integrally formed optical systems. Indeed, since the distance between the two similar images provided by the image splitting lens is controlled by the operative spacing of the lens from the light source (i.e, the more distant the lens from the light source, the farther apart said two images appear) and since it is desired that the distance between the two images be controlled so that said two images are immediately adjacent one another, it is possible, indeed desirable to dispose the image splitting-/collimating lens in close proximity to the light source 2.

Returning now to FIG. 1, a diffuser 5 is provided to scatter the collimated light so that it will illuminate the display matrix 6 in all directions and provide acceptable off axis (wide angle) viewing. However due to the high degree of uniformity of light provided by the image splitting/collimating lens it is not necessary to diffuse the light to the extent necessary in prior art backlight assemblies, and thus the profile of the backlight assembly is further reduced. The backlight assembly 1 further includes lamp control electronics having provisions for lamp starting, a ballast 7 and dimming circuitry.

The light output of the light source 2 disposed behind prior art assemblies such as the liquid crystal display 6 of FIG. 1 is not uniform and will be dependent upon the configuration of the lamps employed and the type of optical system if any, employed. FIG. 2A illustrates the distribution of light intensity directly in front of the serpentine arrangement of fluorescent lamps 2 depicted in FIG. 1, as unenhanced by an optical system (i.e.,

without any collimating, image splitting or diffusing elements). As can be easily discerned from FIG. 2A, unenhanced light emanating from the light source will inevitably lead to areas of localized high intensity of illumination on the array of liquid crystal pixels. This, of course, results in local bright spots, such as b, and local pale spots, such as p, in the displayed image and therefore degraded image quality.

Of course, it is one of the purposes of an optical system, such as 4 in FIG. 1, to redistribute the intensity of radiation from the high intensity areas to the areas of lower intensity while maintaining the total integrated light output from the lamp assembly 2. FIG. 2B depicts the typical distribution of light intensity of the serpentine arrangement of fluorescent lamps 2 of FIG. 2A to which a backreflector 3 has been added. Acceptable uniformity across the viewing surface of the liquid crystal display requires optimization of the backreflector 3 in conjunction with the other optical components. Current backlighting arrangements have been configured to provide acceptable uniformity thereacross, but they lose about one-half of the energy emanating from the lamps. The curve marked as I in FIG. 2C illustrates an intensity of illumination that can be expected from current backlighting designs. In the detailed description which follows hereinafter, a highly efficient optical system will be disclosed that maximizes light output while achieving a high degree of uniformity across the viewing screen, in the manner shown by the curve I'.

The lamp and optical configurations are critical elements in the design of such systems because the characteristics thereof determine the final performance parameters and the overall structural profile of the display. In achieving an optical system characterized by such performance, fluorescent lamps will be capable of operation at a substantially reduced power level, which results in prolonged life. This also reduces heat build-up, thereby reducing thermal management requirements and permitting a more compact design. These improvements not only result in an improved backlighting arrangement in terms of uniformity and intensity, but one that is more reliable and less expensive to build and maintain.

Referring now to FIG. 3, there is depicted therein a matrix array of rows and columns of discrete liquid crystal display picture elements, said matrix array being generally designated by the reference numeral 10. Each liquid crystal display picture element, or pixel, 12 includes two spacedly disposed pixel electrode plates with a light influencing material, such as a liquid crystal composition, operatively captured therebetween. (The electrode plates and the light influencing material will be discussed in detail with respect to FIG. 5.) Each of the pixels 12 further includes a threshold switching device or a plurality of threshold switching devices for selectively applying an electric field across the liquid crystal composition when the electric field exceeds a predetermined threshold value.

More specifically, the matrix array 10 which defines the liquid crystal display of the instant invention includes a first set of X address lines 20, 22 and 24: a second set of Y address lines 26, 28 and 30; and a plurality liquid crystal picture elements 32, 34, 36, 38, 40, 42, 44, 46 and 48. The display further includes at least one isolation or addressing element 50, 52, 54, 56, 58, 60, 62, 64 and 66 operatively associated with and electrically connected to each respective one of the picture elements. As should be readily apparent to the reader from even a cursory review of FIG. 1, the X address lines 20, 22 and 24 and the Y address lines 26, 28 and 30 cross over one another at an angle so as to define a plurality of spaced crossover points associated with respective ones of the liquid crystal picture elements 32-48. The picture elements are formed on a transparent substrate, such as glass, and are distributed thereover in spacedly disposed relation so as to define interstitial spaces therebetween.

As can be ascertained from a perusal of FIGS. 3 and 4, each of the threshold devices 50-66 is preferably coupled in nonopposing series relation with a first one of the pixel electrodes. This type of switching arrangement will now be described in greater detail with respect to FIG. 4. In FIG. 4, the matrix array 10' includes a plurality of substantially parallel address line pairs 20, 20', 22, 22', 24 and 24' which are the row select lines and a plurality of substantially parallel column address lines 26 and 28. The column address lines 26, 28, and 30 cross the row select address line pairs at an angle and are spaced from the row select address line pairs to form a plurality of crossover points therewith. Preferably, the column address lines cross the row select line pairs at an angle which is substantially perpendicular thereto.

Since, as mentioned hereinabove, each of the pixels are identical, only pixel 12 will be described in detail in the following paragraphs. Pixel 12, as can be seen from the figures, includes a pair of threshold devices 74 and 76 which are electrically coupled together at common node 78. The threshold devices 74 and 76 are preferably diodes and are electrically coupled together in nonopposing series relationship between the row select address line pair 20 and 20'. Although the threshold devices, in accordance with the preferred embodiment of the invention are diodes, said devices can be of any type which provides a high impedance to current flow when reverse biased and a comparatively low impedance to current flow when forward biased. Therefore, any bidirectional threshold switch or field effect transistor can be utilized with equal advantage. Of course, more conventional electrical interconnections would be employed with field effect transistors.

The picture element or pixel 12 further includes a pair of electrode plates 80 and 82 which are spaced apart and facing one another. Operatively disposed in the space between the electrodes 80 and 82 is a light influencing material 84. The term "light influencing material" is defined and will be used herein to include any material which emits light or can be used to selectively vary the intensity, phase, or polarization of light either being reflected from or transmitted through the material. In accordance with the preferred embodiment of the invention, the light influencing material is a liquid crystal display material, such as a nematic liquid crystal material. In any event, the electrodes 80 and 82 with the liquid crystal material 84 disposed therebetween form a storage element 86 (or capacitor) in which electric charge can be stored. As illustrated, the storage element 86 is coupled between the common node 78, formed by the electrically connected diodes 74 and 76, and the column address line 26.

Still referring to FIG. 4, the display 10 further includes a row select driver 90 having outputs R-1*a*, R-1*b*, R-2*a*, R-2*b*, R-3*a*, and R-3*b* electrically coupled to the row select line pairs 20, 20', 22, 22', 24, and 24'. The row select driver 50 provides drive signals at the outputs thereof to apply first operating potentials which are substantially equal in magnitude and opposite in polar-

ity between the row select address line pairs to forward bias the threshold devices to in turn facilitate the storage of electric charge in the storage elements coupled thereto. The row select driver also applies second operating potentials which are substantially equal in magnitude and opposite in polarity between the row select address line pairs to reverse bias the threshold devices to facilitate the retention of the electric charge stored in the storage elements coupled thereto.

Lastly, the electronic display 10 includes a column driver 92. The column driver 92 includes a plurality of outputs, C1 and C2, which are coupled to the column address lines 26 and 28 respectively. The column driver is adapted to apply a charging potential to selected ones of the column address lines for providing electric charge to be stored in selected storage elements during the application of the first operating potentials to the row select address line pairs by the row select driver 50.

It is preferred that the matrix array of rows and columns of picture elements that combine to make up the improved electronic display 10 of the instant invention utilize a "balanced drive" scheme for addressing each discrete one of the pixels thereof. In this driving scheme, the operating potentials applied to the row select address line pairs are always substantially equal but opposite in polarity. Assuming that the current-voltage characteristics of each of the diodes are substantially equal, a voltage of substantially zero volts will be maintained at the common node 78, at least when the diodes are forward biased. Thus, the voltage applied on the column address line 26 to charge storage element 86 no longer needs to take into account the voltage drop across and/or parasitic charge build-up on one or both of the diodes 74 and 76. Therefore, each pixel in the matrix array of rows and columns may be charged to a known and repeatable value regardless of its position in that matrix array. This permits improved gray scale operation resulting in at least 15 levels of gray scale in large area active matrix displays of the twisted nematic liquid crystal type using normal fluorescent back illumination. The pixels can also be charged more rapidly since the retained charge in the diodes associated with each pixel when they are reverse biased need not be initially dissipated to charge the storage elements. This is because this charge is dissipated when the diodes are first forward biased. A complete description of this driving scheme can be found in U.S. Pat. No. 4,731,610 issued on Mar. 15, 1988 to Yair Baron et al and entitled "Balanced Drive Electronic Matrix System And Method Of Operating The Same", the disclosure of which is incorporated herein by reference.

Turning now to FIG. 5, there is depicted in a fragmentary perspective view, one preferred embodiment of the instant invention. In this embodiment of the invention, the image splitting/collimating lens 102 is operatively disposed so as to provide for a low profile electronic display assembly 11. The low profile or depth dimension of the display is especially important and is dependent on the type of lighting assembly, the material from which the threshold devices are fabricated, the on-board electronics, the multiplexing schemes, and most importantly, the optical arrangement by which light is diffused, collimated and transmitted to the viewing audience. It is, inter alia, the depth dimension of liquid crystal displays that has been significantly improved by the inventive concept set forth herein.

There are four basic elements which combine to form the electronic display 11 depicted in FIG. 5. The uppermost element is the generally rectangularly-shaped glass panel 10 upon which the rows and columns of active matrix liquid crystal picture elements as well as the associated drive circuitry, described in the preceding paragraphs, are disposed. The lowermost element is the thin, generally rectangularly-shaped back reflector panel 98 upon the interior surface of which one or more thin film layers of highly reflective material, such as aluminum or silver and a light transparent material having a low index of refraction, are deposited. Disposed immediately above the highly reflective panel 98 is an array of light sources 100 from which radiation emanates and either passes directly towards the matrix array of picture elements or is reflected off of the highly reflective panel and then passes upwardly toward said matrix array. Finally, the improved image splitting/collimating lens 102 of the instant invention is operatively located between the array of light sources 100 and the matrix array of picture elements 10. It is the combination of these elements which define the profile, preferably the low profile, of the electronic display of the instant invention.

More specifically, it is important to note that lighting is one of the critical parameters which is employed in assessing the visual appearance of a liquid crystal display. Not only is it essential that the image of the display appear clear and bright to the viewers thereof, but it is also important that the image be substantially as clear to viewers disposed at an angle relative to the vertical plane of the viewing screen of the display. The structural and optical relationship existing between the array of light sources and the image splitting/collimating lens 102 helps to determine the clarity and viewing angle of the display.

In the preferred embodiment of the invention illustrated in FIG. 5, the array of light sources 100 is configured as one elongated, serpentine fluorescent lamp (although it must be appreciated that a plurality of discrete elongated tubular lamps could be employed without departing from the spirit or scope of the instant invention) arranged in a specific pattern or lighting configuration and having each section of lamp disposed in a generally horizontal plane. More specifically, the array, regardless of configuration, will be arranged to uniformly distribute radiation emanating therefrom over the entire surface area of the matrix of rows and columns of picture elements 105. To this end, the lighting array is shaped in a serpentine pattern which may include a plurality of elongated lamps, such as *100a*–*100e*, each lamp of which has a longitudinal axis parallel to the longitudinal axis of the other major lamp sections The length of each longitudinal lamp axis is generally coextensive with the length dimension of the matrix array of picture elements. The configuration of the lighting array 100 also includes curved end sections, such as *101c*–*101d*. The number of the elongated axial sections of the lamps and the number of the curved end sections of the lamps must be sufficient to bathe the entire width dimension of the matrix array of picture elements 105 with a uniform shower of illumination.

The image splitting/collimating lens 102 is formed as an integral unit, vis-a-vis, prior art image splitters and collimators which were formed as two distinct elements. The integrally formed image splitting/collimating lens is, as discussed hereinabove, fabricated of Optical Lighting Film (registered Trademark of 3M Scotch) which is subsequently laminated onto a transparent substrate such as glass, a ceramic or plastic. By employ-

ing an integrally formed image splitting/collimating lens it is thus possible to achieve two desired optical effects without an increase in the profile of the display. Indeed, since the distance between the two similar images provided by the image splitting effect of the image splitting/collimating lens is controlled by the operative spacing of the lens from the light source (i.e, the more distant the lens **102** from the light source, the farther apart said two images appear) and since it is desired that the distance between the two images be controlled so that said two images are immediately adjacent one another, it is possible, indeed desirable, to dispose the image splitting/collimating lens in close proximity to the light source **100**. As is illustrated in FIG. **5**, the image splitting/collimating lens can be used in conjunction with a diffuser **104** to further enhance the uniformity of the light emanating from the light source **100**.

In a second preferred embodiment of the invention illustrated in FIG. **6**, the array of light sources **200** is configured as square, helical fluorescent lamp (although it must be appreciated that a plurality of discrete elongated tubular lamps could be employed without departing from the spirit or scope of the instant invention) arranged in a specific pattern or lighting configuration and having each section of lamp disposed in a generally horizontal plane. As stated hereinabove, the array, regardless of configuration, will be arranged to uniformly distribute radiation emanating therefrom over the entire surface area of the matrix of rows and columns of picture elements **205**. To this end, the lighting array is shaped in a square, helical pattern which may include at least a pair of squarely configured, elongated lamps, such as **200*a*–200*b***, each portion of each squarely configured lamp being parallel to the squarely configured portions of the other lamp. The configuration of the lighting array **200** also includes curved sections, such as **201*c*–201*d***. The number of the elongated portions of the lamps is generally equal to eight in the square helical configuration.

The image splitting/collimating lens **202** is formed as an integral unit, vis-a-vis, prior art image splitters and collimators which were formed as two distinct elements. The integrally formed image splitting/collimating lens is, as discussed hereinabove, fabricate of Optical Lighting Film (registered Trademark of 3M Scotch) which is subsequently laminated onto a transparent substrate such as glass, a ceramic or plastic. By employing an integrally formed image splitting/collimating lens it is thus possible to achieve two desired optical effects without an increase in the profile of the display. Indeed, since the distance between the two similar images provided by the image splitting effect of the image splitting/collimating lens is controlled by the operative spacing of the lens from the light source (i.e, the more distant the lens **202** from the light source, the farther apart said two images appear) and since it is desired that the distance between the two images be controlled so that said two images are immediately adjacent one another, it is possible, indeed desirable, to dispose the image splitting/collimating lens in close proximity to the light source **200**. As is illustrated in FIG. **6**, the image splitting/collimating lens can be used in conjunction with a diffuser **204** to further enhance the uniformity of the light emanating from the light source **200**.

Turning now to FIG. **7**, there is depicted therein a cross-sectional view of FIG. **5**, said cross-sectional view provided to demonstrate the manner in which rays of light "r" emanating from the lamps **100*b*–100*c*** of the

lighting configuration **100** are collimated to present a sharp image to the viewing audience of the liquid crystal display of the instant invention. More particularly, there is depicted a plurality of lamps, such as **101*b*, 101*c***, and **101*d***, of the embodiment of the lighting configuration wherein the longitudinal axes thereof are disposed in substantially parallel alignment. As can be seen from a perusal of FIG. **7**, the rays of light "r" emanating from the three parallel, but spacedly disposed lamps are directed upwardly through the relatively thin image splitting/collimating lens **102**. The upper surface, the surface opposite the light source **100**, of the image splitting/collimating lens **102** is engineered so as to comprise a series of aligned multi-faceted prisms **103**. The prisms **103** are aligned such that the longitudinal extents thereof are substantially parallel to the longitudinal extents of the substantially parallel lamps **100*a*** and **100*b***. At both the planar air-to-material interface **102*x*** and the faceted L material-to-air interface **102*y*** thereof, the rays of light are collimated and transmitted to the viewers in that collimated fashion. Note that for purposes of illustrating the collimating effect of the lens array of the instant invention, neither the reflector plate **98** nor the matrix array **10** of rows and columns of liquid crystal picture elements are depicted in FIG. **7**. Of course, it is the aligned facets of said prisms **103** that provide the image splitting effect which is critical to the improved performance provided by the instant invention.

FIG. **8** is presented to schematically illustrate how the above-referenced aligned facets of the prisms **103** inherently operate to provide the image splitting effect. This, of course, also illustrates the inherent characteristics of operation of the aforesaid 3M Optical Lighting Film when used in this invention. As illustrated with reference to a segmented arc of lamp **100*c*** having a mid-point B and extremities A and C (these points being designated for convenience of illustration, it being understood that lamp **100*c*** is a circular tube), certain rays of light are reflected backwardly while others are allowed to exit in collimated fashion from lens **102**. To the observer located at "eye" this inherently results in a "split image" **1** and **2**, the spacking of which, as aforesaid, is governed by the distance between the lamp **100*c***, and the lens **102**.

While the foregoing paragraphs have described the inventive concept set forth in the this specification, the instant inventors do not intend to have the disclosed invention limited by the detailed embodiments, drawings or description; rather, it is intended that the instant invention should only be limited by the scope of the claims which follow hereinafter, as well as all equivalents thereof which would be obvious to those routineers of ordinary skill in the art.

What is claimed is:

1. In a backlit liquid crystal display which includes a source of light; a matrix array of rows and columns of liquid crystal picture elements spacedly disposed from one side of said light source; and means for collimating light, said collimating means operatively disposed between said light source and said matrix array of rows and columns of liquid crystal picture elements; said liquid crystal display capable of providing an image to a remotely positioned observer; the improvement comprising, in combination:

an integral collimating and image splitting means for collimating light from said light source and for refracting light rays emanating from said light source to provide two similar images thereof,

thereby enlarging the area effectively illuminated by said light source, whereby a bright, uniform, light distribution is provided in a low profile assembly.

2. A display as in claim 1, further including a backreflector operatively disposed on the side of said light source opposite said image splitting/collimating lens.

3. A display as in claim 1, further including means for diffusing light emanating from said light source, said light diffusing means operatively disposed between said image splitting/collimating lens and said rows and columns of liquid crystal picture elements.

4. A display as in claim 1, wherein said light source is a single, elongated, serpentined, tubular lamp arranged in a series of elongated parallel lobes.

5. A display as in claim 1, wherein said light source is a multi-tube lamp array wherein each of said lamps are elongated tubular lamps arranged in substantially parallel fashion.

6. A display as in claim 1, wherein said light source is at least a pair of tubular lamps arranged in a square helical configuration.

7. A display as in claim 1, wherein said image splitting/collimating lens comprises a film having prisms formed on one face thereof.

8. A display as in claim 7, wherein the image splitting/collimating film is laminated to a substrate.

9. A display as in claim 8, wherein said substrate is a thin transparent substrate.

10. A display as in claim 9, wherein the substrate is glass.

11. A display as in claim 1 wherein said integral collimating and image splitting means includes a thin film having faceted prisms formed on one face thereof and wherein said light rays are refracted by the said facets of said prisms.

12. A display as in claim 1, wherein the distance between said two similar images is controlled by the operative spacing of said image splitting/collimating means from said light source.

13. A display as in claim 12, wherein said image splitting/collimating means is operatively spaced from said light source so that said two similar images are immediately adjacent one another.

14. A display as in claim 1, wherein the liquid crystal display is an active matrix liquid crystal display.

15. A display as in claim 1, wherein each liquid crystal picture element comprises a pair of electrodes having liquid crystal material disposed therebetween and at least one threshold device connected at one of the terminals thereof to one of said electrodes.

16. A display as in claim 15, wherein a pair of threshold devices are provided, said threshold devices electrically coupled together at a common node in nonopposing, series relationship.

17. A display as in claim 15, wherein said at least one threshold device comprises a transistor formed from deposited layers of semiconductor material.

18. A display as in claim 15, wherein the threshold devices comprise diodes formed from deposited layers of semiconductor material.

19. A display as in claim 18, wherein the semiconductor material is an amorphous silicon alloy material.

20. A display as in claim 1, wherein the light source comprises lamps arranged in two orthogonal directions.

21. A display as in claim 20, further including two image splitting/collimating lenses arranged to provide perpendicular image splitting effects.

22. A display as in claim 21, wherein said image splitting/collimating lenses each comprise thin films disposed one atop the other, and wherein the dimension in which one of said image splitting/collimating lenses provides an image splitting effect is offset by 90 degrees relative to the other lens.

* * * * *

EXHIBIT G

IBM Technical Disclosure Bulletin Vol. 33 No. 1B June 1990

[redacted]

359/69

POLARIZED BACKLIGHT FOR LIQUID CRYSTAL DISPLAY

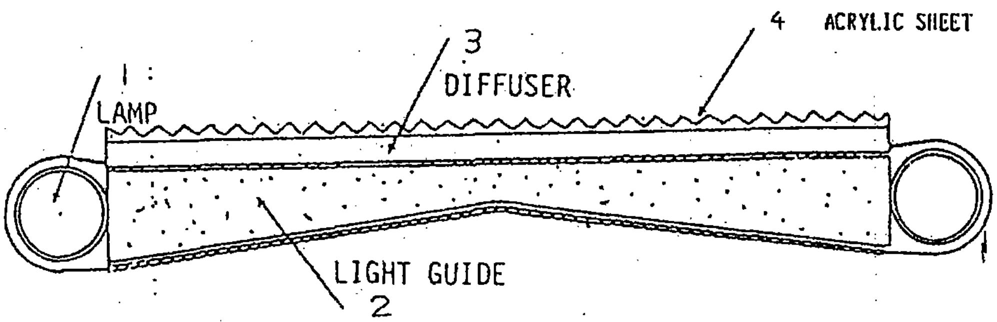


Fig. 1

Disclosed is a backlight device for a transmissive liquid crystal display. This device emits a polarized light whose polarizing axis is parallel with that of a polarizer located on one side of a liquid crystal cell and near the backlight so that the light can pass through the polarizer more than a non-polarized light.

Light which has no polarization from a backlight into the liquid crystal cell has uniform electromagnetic field for 360 degrees. Theoretically, 50 percent of electromagnetic field is absorbed and 50 percent is transmitted by the polarizer. In actuality, 58 percent of electromagnetic field is absorbed and 42 percent is transmitted.

With reference to Fig. 1, the backlight disclosed herein consists of fluorescent lamps 1, an acrylic transparent light guide 2, an acrylic translucent diffuser 3, and an acrylic sheet 4 which has an indented cross-section. Light emitted from the fluorescent lamps 1 is conducted through the light guide 2 by the law of total reflection and is scattered by the diffuser 3 for the purpose of uniform luminance. The acrylic sheet 4 not only optimizes the emissing direction of light by varying the indentation angle but also polarizes the light. Fig. 2 shows a rotation angle versus luminance measured with a polarizing prism. In this case, the acrylic sheet has a indentation angle of 90

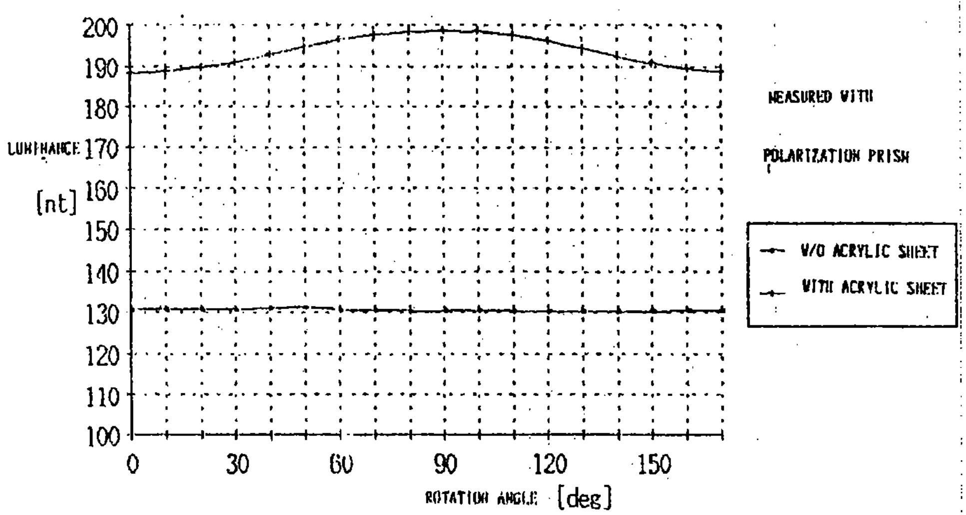


Fig. 2

degrees. This chart shows that luminance changes according to the rotation angle, that is to say, the light has polarization. Five percent of luminous increase is achieved by arranging a polarizing axis of the polarizer and transmissive axis of the acrylic sheet parallel.

In the above example, 5 percent of luminous increase is achieved in consequence of 5 percent of polarization of light. In case linear polarization of light is accomplished, the backlight device makes it possible to eliminate the polarizer located on the backlight side of the liquid crystal cell.

EXHIBIT H

United States Patent [19]

Hamada

[11] Patent Number: 5,052,783

[45] Date of Patent: Oct. 1, 1991

[54] **PROJECTION TYPE IMAGE DISPLAY APPARATUS**

[75] Inventor: Hiroshi Hamada, Nara, Japan

[73] Assignee: Sharp Kabushiki Kaisha, Osaka, Japan

[21] Appl. No.: 423,335

[22] Filed: Oct. 18, 1989

[30] Foreign Application Priority Data

Oct. 26, 1988 [JP] Japan 63-270181

[51] Int. Cl.⁵ G02F 1/13

[52] U.S. Cl. 359/40; 359/54; 359/49

[58] Field of Search .... 350/331 R, 334, 339 R, 350/345, 114, 347 V

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Primary Examiner—Rolf Hille
Assistant Examiner—Tan Ho

[57] ABSTRACT

In a liquid crystal image display apparatus, an image of pixels of a liquid crystal display panel are projected onto a projection surface. The apparatus includes a light source, the liquid crystal display panel, microlens arrays provided respectively at a side of the liquid crystal display panel facing the light source and at another side thereof facing the projection surface, and a condenser lens provided between the light source and the microlens array located at the light source side of the display panel. The microlens arrays include a plurality of microlenses provided in positions corresponding to the plurality of pixels of the liquid crystal display panel, and pitches of the microlenses of the microlens array at the light source side are set to be larger than pitches of the pixels, while the pitches of the microlenses of the microlens array at the projection surface side are set to be smaller than those of the pixels.

18 Claims, 7 Drawing Sheets

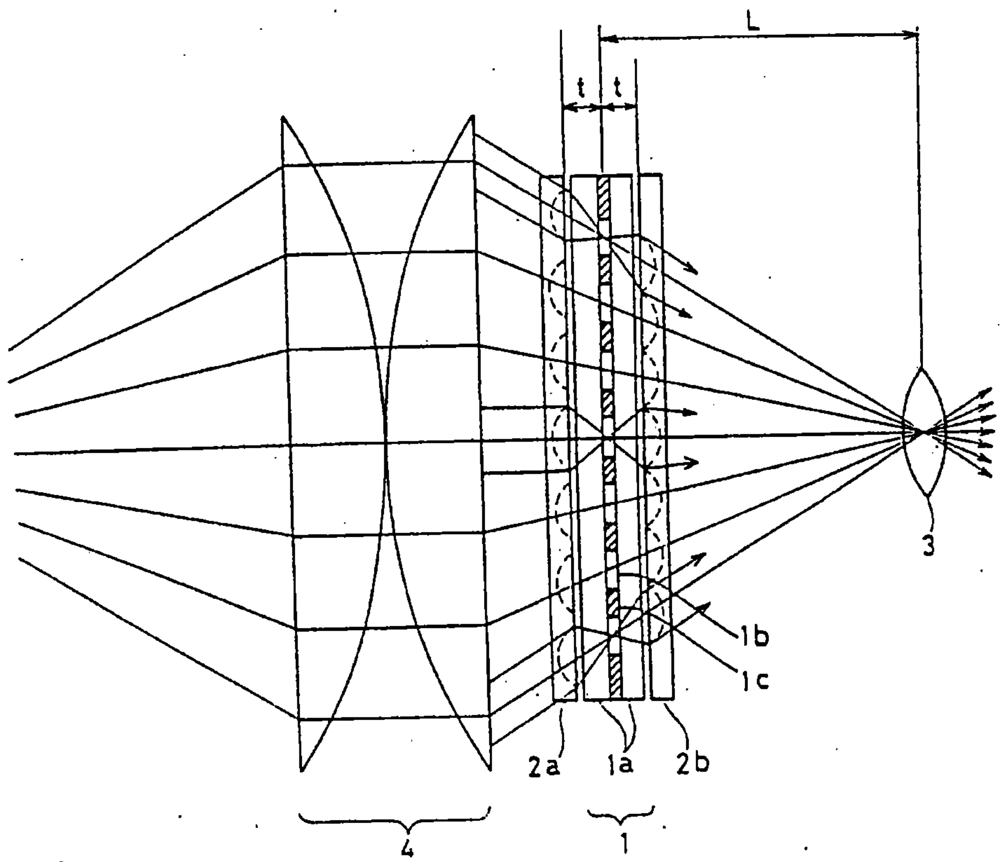


FIG.1 PRIOR ART

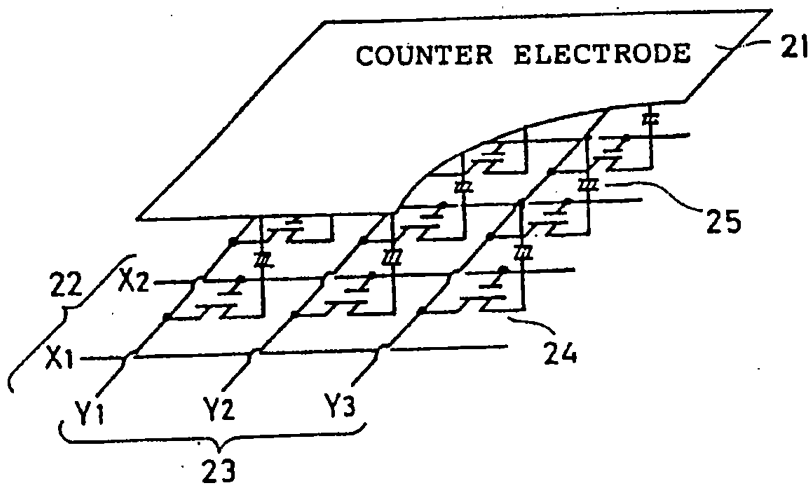


FIG.2 PRIOR ART

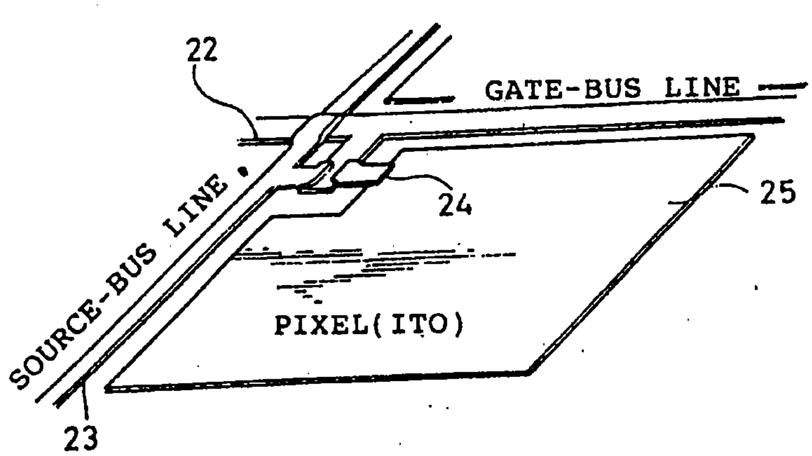
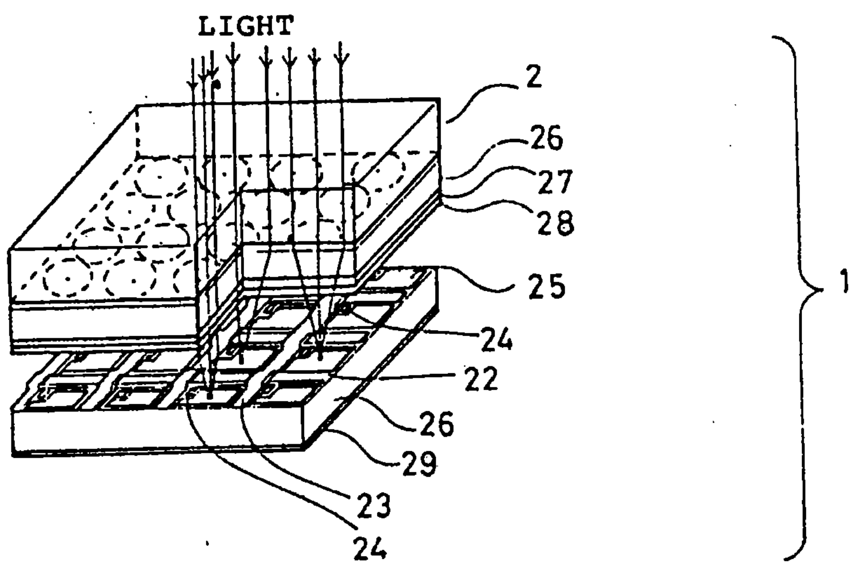


FIG.3 PRIOR ART



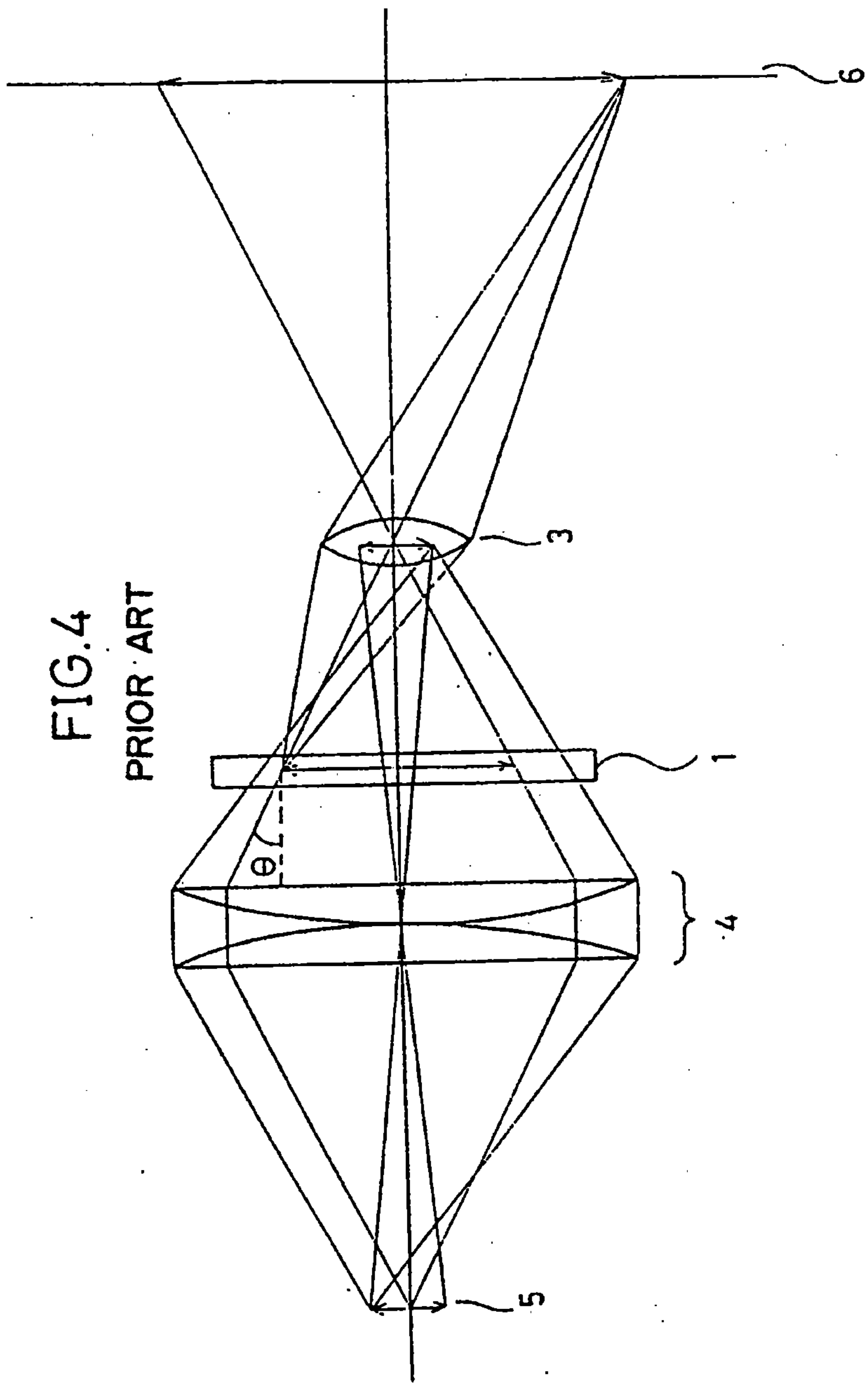


FIG.4
PRIOR ART

FIG.5B PRIOR ART

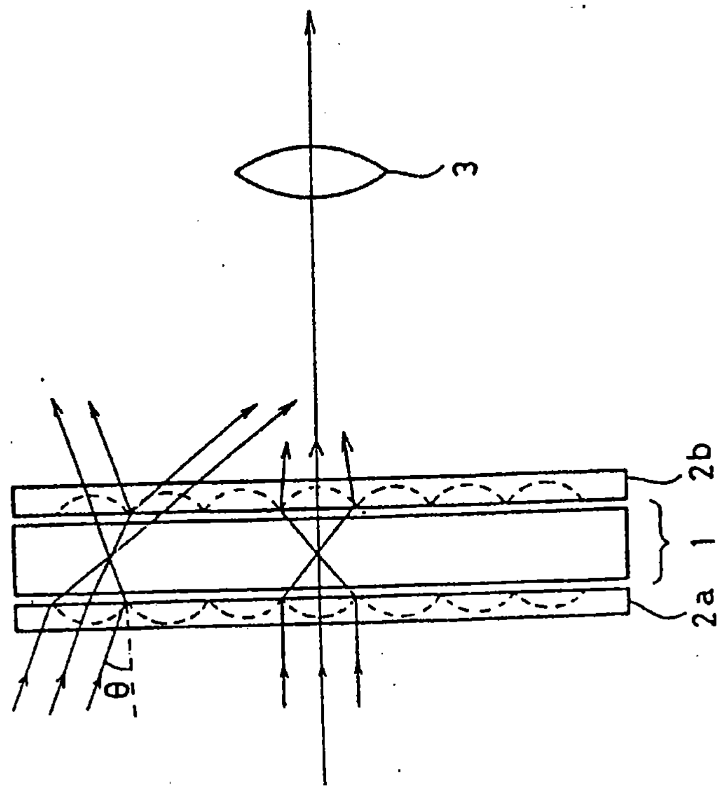
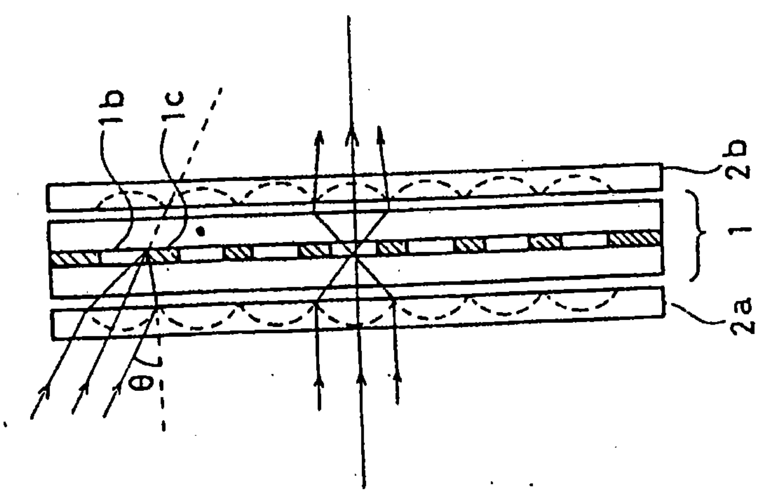


FIG.5A PRIOR ART



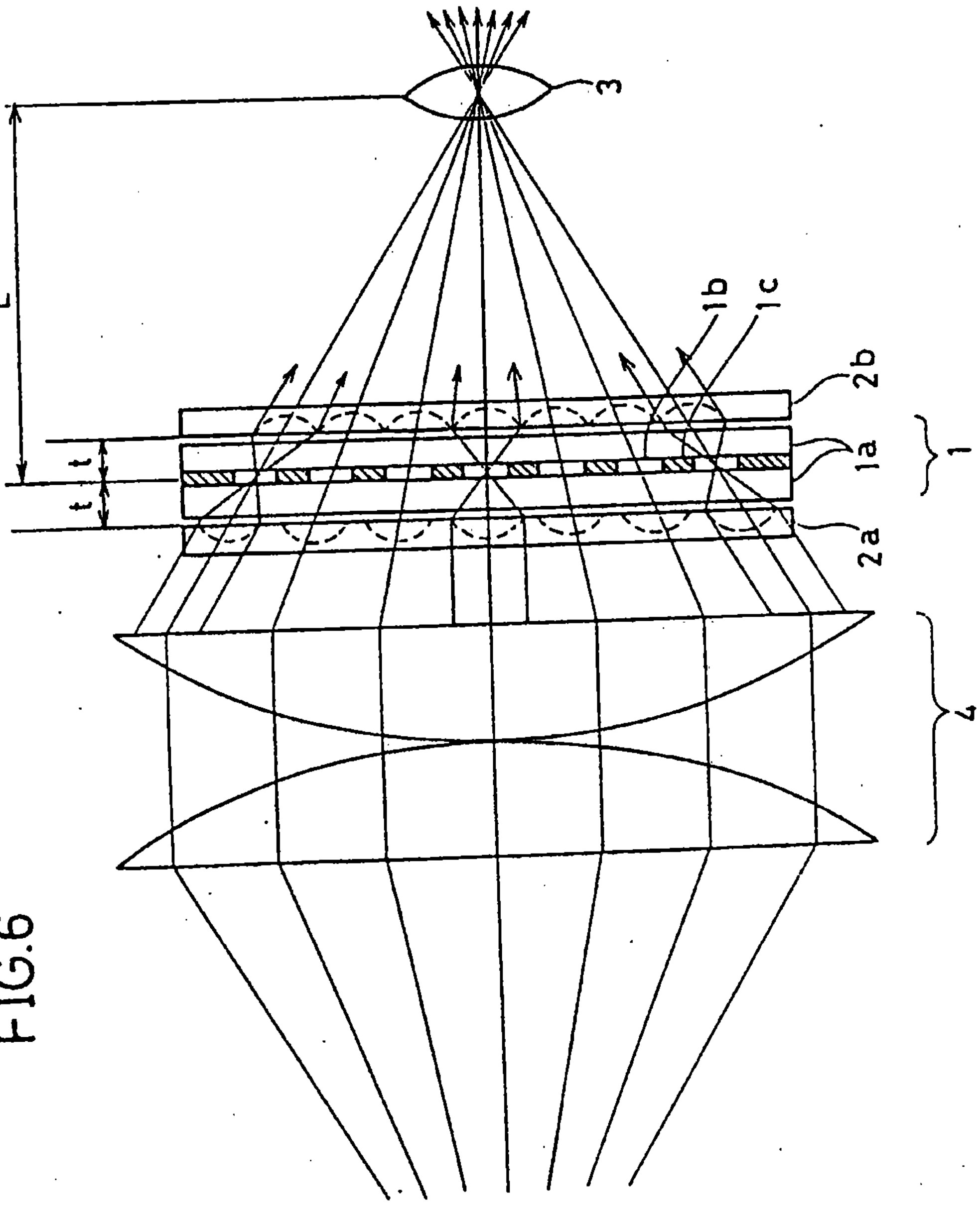


FIG.6

FIG.7

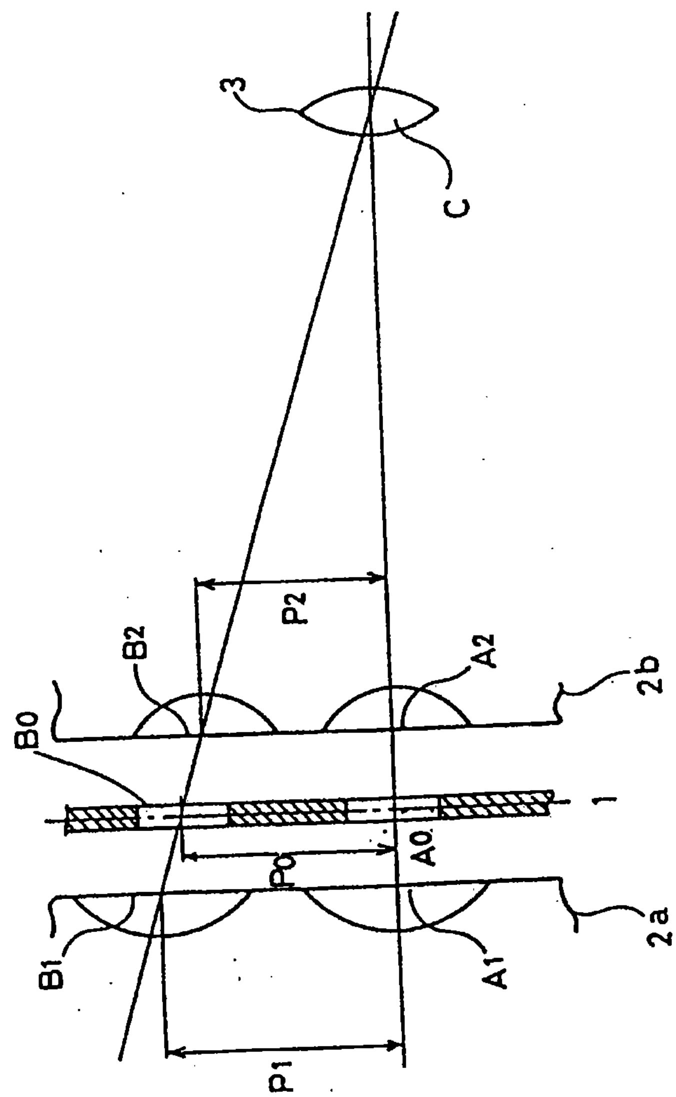
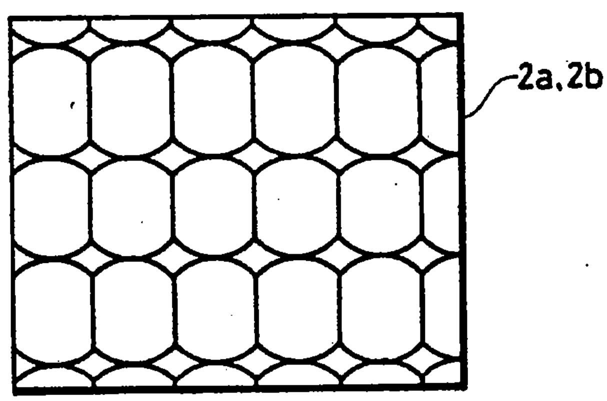


FIG.8



PROJECTION TYPE IMAGE DISPLAY APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a projection type image display apparatus comprising non-emissive display panels of a matrix type (e.g., liquid crystal display panels) and microlens arrays. More particularly, it relates to the projection type image display, apparatus in which a bright display is achieved over the entire region of the panel.

DESCRIPTION OF THE BACKGROUND ART

A non-emissive display panel employed in the present invention, which does not emit light per se, has its light transmittance varied by a driving signal. Images and characters are displayed by modulating the intensity of light emitted from an external light source. Examples of the non-emissive display panel, are a liquid crystal display panel, an electrochromic display, and a display using PLZT as an electro optical material or the like. The liquid crystal display panel is particularly widely used for portable TV, word processors and the like. Minimum display units called pixels are regularly provided in such a panel. Application of individual drive voltages to the respective pixels causes the images and characters to be displayed. As a method of applying the individual drive voltages to the respective pixels, there exists a simple matrix driving method and an active matrix driving method. FIG. 1 shows a schematic equivalent circuit of a liquid crystal display panel employing active matrix driving. Referring to FIG. 1, the active matrix driving type liquid crystal display panel comprises TFTs 24 provided in matrix at respective intersections of X electrodes 22 and Y electrodes 23, with liquid crystal elements 25 forming pixels connected to the TFTs 24. FIG. 2 is a diagram illustrating in detail the periphery of one of the pixels shown in FIG. 1. Referring to FIG. 2; a thin film transistor TFT 24 is provided at an intersection of a gate bus line corresponding to one of the X electrodes 22 and a source bus line corresponding to one of the Y electrodes 23, with a drain thereof connected to the pixel electrode 25.

In the active matrix type liquid crystal display apparatus, driving signal lines, gate bus lines and source bus lines, for supplying the drive voltages to the respective pixels need be provided among the pixels. Therefore, the ratio of a pixel region occupying a screen (aperture) decreases. A portion of the light illuminating the panel, which impinges on portions other than the pixel region, does not contribute to the display and thus becomes useless. Therefore, there was a disadvantage that the screen became darker as the aperture of the panel decreased even if the same light source was employed.

To eliminate this disadvantage, a microlens array (in which microlenses are regularly arranged in two dimensions) is employed to the display panel. Convergence of the illuminating light on the pixel region results in enhanced brightness of the display screen. The details of this process is disclosed in, for example, Japanese Laid Open Patent Nos. 60-165621-165624 and 60-262131.

FIG. 3 is a perspective view illustrating a state that the microlens array 2 is attached to the active matrix type liquid crystal display apparatus 1. Referring to FIG. 3, the active matrix type liquid crystal display apparatus 1 comprises a pixel electrode 25, shown in

FIG. 1, an aligning layer/counter electrodes 28 provided on the pixel electrode 25 (now shown) and on the place opposing the pixel electrode 25, a glass substrate 26 provided below the pixel electrode 25, a color filter 27 provided above the aligning layer/counter electrode 28, and another glass substrate 26 provided above the color filter 27.

As shown in FIG. 3, each of the microlenses is provided in a position corresponding to one pixel of the display panel. The light from the light source impinges on each pixel electrode 25 through each microlens. Thus, pitches of the microlenses constituting the microlens array 2 have been made equal to pitches of the pixels of the display panel 1.

FIG. 4 is a diagram illustrating a principle of image projection in a conventional projection type image display apparatus. A projection optical system being the same as that used in a slide projector, is employed. The non-emissive display panel 1 is provided in place of a slide, and an image displayed on the display panel is projected in magnification by employing the light source. An image of the light source 5 is formed in a projection lens 3 in this optical system, as shown in FIG. 4. The image on the display panel 1 is projected on a screen 6 through the projection lens 3. In this case, light from the light source 5 is converged by a condenser lens 4 at the periphery of the display panel 1 (i.e., a position apart from an optical axis in this figure,) but passes obliquely rather than normally to the display panel 1. This angle θ deviated from the right angle becomes larger This as the display panel 1 becomes larger or a distance between the display panel 1 and the projection lens 3 becomes shorter.

FIGS. 5A and 5B are enlarged views of the periphery of the display panel 1 shown in FIG. 4. Referring to the FIGS. 5A and 5B, the display panel 1 comprises pixel regions 1*b* and bus lines or TFT regions 1*c*. Microlenses, arrays 2*a* and 2*b* including a plurality of microlenses arranged in the same pitches as those of the pixels of the display panel, are provided respectively at opposite sides of the display panel 1, i.e., at the side facing the light source with the other side facing the projection lens.

Referring to these figures, in the case that the pitches of the pixels of the display panel are equal to those of the microlenses of the microlens arrays, an increase of the deviation angle 0 causes the following two phenomena.

(1) The light from the light source is focused near the pixels by the microlenses at the side facing the light source to form an image of the light source. However, if the angle θ is large, the image of the light source extends beyond the pixel regions 1*b*, as shown in FIG. 5A. The light impinges absorbed or scattered on non-display region and thus becomes useless.

(2) As shown in FIG. 5B, the light passing through the center of the microlenses 2*a* at the side facing the light source does not pass through the center of the microlenses 2*b* at the side facing the projection lens. Therefore, the incident light changes its direction so as to not be directed toward the projection lens 3. The angle θ between the optical axis and the angle of the incidence of the light becomes larger as it becomes distant from the center of the screen. Thus, a projected image becomes darker as it becomes distant from the center of the screen due to these phenomena.

SUMMARY OF THE INVENTION

It is an object of the present invention to prevent darkening of even the periphery of a projected image in a projection type image display apparatus.

It is another object of the present invention not to prevent making pitches of microlenses of a microlens array equal to pitches of pixels of a liquid crystal display apparatus in the projection type image display apparatus.

It is a further object of the present invention to have light, which passes through the center of microlenses at the side facing a light source, pass through the pixels and through the center of microlenses at the side facing a projection lens, in the projection type image display apparatus.

The above described objects of the present invention are achieved by the fa . . t'he projection type image display apparatus comprises the ... ng. ...hat is, the projection type image display apparatus, for projecting light from the light source onto a non-emissive display portion according to the present invention and then projecting an image of the display portion on a predetermined projection screen, comprises a display panel in which a plurality of pixels arranged apart from each other by a predetermined first spacing in a matrix, a first microlens array provided at the side of the display panel facing the light source, which includes a plurality of microlenses arranged apart from each other by a predetermined second spacing in corresponding positions of the plurality of pixels on the display panel, and a second microlens array provided at the other side of the display panel facing the projection screen, which includes a plurality of microlenses arranged in corresponding positions of the plurality of pixels on the display panel. Furthermore, the first and second spacings are selected to be different from each other.

Since the projection type image display apparatus according to the present invention comprises the above described elements, pitches of the microlenses facing the light source differs from pitches of the pixels on the display panel. Therefore, the pitches of the microlenses are determined such that the light from the light source passing through the periphery passes through the center of the corresponding pixels on the display panel. As a result, even the periphery of a projected image does not become darker in the projection type image display apparatus.

Preferably, a condenser lens is provided between the light source and the display portion to focus the light from the light source on the side facing the projection screen, and the second spacing is selected to be larger than the first spacing; and further, the plurality of microlenses of the second microlens array are arranged apart from each other by a predetermined third spacing, which is selected to be smaller than the first spacing.

More preferably, since the projection type image display apparatus according to the present invention comprises the above described elements, the light passing through the center of the microlenses at the side facing the light source passes through the center of the microlenses at the side facing the projection lens. Therefore, the incident light is effectively directed to the projection lens without changing its direction. Consequently, the projected image over the entire screen has a predetermined brightness in the projection type image displa paratus.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic equivalent circuit diagram of a liquid crystal display panel of active matrix type;

FIG. 2 is an enlarged view of the periphery of one of the pixels of the liquid crystal display panel shown in FIG. 1;

FIG. 3 is a perspective view illustrating a state that a microlens array is attached onto an active matrix type liquid crystal display apparatus;

FIG. 4 is a diagram illustrating an image projection optical system of the projection type image display apparatus;

FIGS. 5A and 5B are enlarged views of the display panel portion shown in FIG. 4;

FIG. 6 is a top view of the projection type image display apparatus to which the present invention is applied;

FIG. 7 is a view illustrating a relationship between pitches of pixels of the display panel and those of microlenses of the microlens array; and

FIG. 8 is a plan view of a microlens array in which boundaries of each microlens are partially fused.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 6, a liquid crystal display panel 1 of the matrix type and an equivalent type and equivalent type has pixels which are display units arranged regularly in a portion sandwiched between substrates *1a*. A microlens array *2a* having larger pitches than those of the pixels is attached to the front of the liquid crystal display panel 1. A condenser lens 4 and a light source 5 (not shown) are provided in front of the microlens array *2a*. A microlens array *2b* having smaller pitches than those of the pixels is attached to the rear of the liquid crystal display panel 1. A projection lens 3 and a screen 6 (not shown) are provided further in the rear of the panel. It is now assumed that a distance from the center of the liquid crystal display panel 1 to the projection lens 3 is represented by L. A distance between a surface in which the pixels of the display panel 1 are arranged and a plane surface in which the microlens array *2a* and *2b* is provided is represented by t, which is nearly equal to a thickness of the substrate *1a* of the display panel 1.

As shown in FIG. 6, the microlens arrays *2a* and *2b* display panel 1. This arrangement, however, is made only for convenience of a description thereof, and thus, in practicality, there is no spacing between these microlens arrays.

Light from the light source, not shown, is converged by the condenser lens 4 and transmitted through the microlens array *2a*, the liquid crystal display panel 1 and the micrlens array *2b* to be imaged on the projection lens 3 and projected on the screen, not shown.

A description will be given of the relationship between a lens pitch of the micrlens arrays and a pixel pitch of the liquid crystal display panel 1 with reference to FIG. 7. For simplification, the relationship will be described between a pixel at the center of the screen (on an optical axis) and an adjacent pixel. A central portion of the pixel at the center of the screen is represented by A_0, the central portions of the corresponding micro-

lenses are respectively represented by A_1 and A_2, the adjacent pixel is B_0, and the central portions of their corresponding microlenses are B_1 and B_2. Since a liquid crystla layer is several μm thich, it is negligible in this figure.

A length between $\overline{A_0B_0}$ is represented by P_0 (the pixel pitch), and $\overline{A_1B_1}=P_1$, $\overline{A_2B_2}=P_2$ (the pitches of the microlenses).

$\overline{A_0A_1}$ and $\overline{A_0A_2}$ both are equal to the value t/n, which is obtained by dividing the thickness t of the substrate of the liquid crystal panel by a refractive index n of the substrate in order to convert the t into an optical path length in the air.

Assuming that the location of the projection lens 3 on the optical axis is C, triangles A_0B_0C, A_1B_1C and A_2B_2C are similar to one another.

Therefore, the following equalities are given:

$$P_1/P_0 = \overline{A_1C}/\overline{A_0C} = (L + t/n)/L = 1 + t/(n \cdot L) \quad (1)$$

$$P_2/P_0 = \overline{A_2C}/\overline{A_0C} = (L - t/n)/L = 1 - t/(n \cdot L) \quad (2)$$

That is, if the pixel pitch and the pitches of the microlenses are selected in such relationship as expressed in the above equalities (1) and (2), the light from the light source passes through the central portions of the microlenses and the pixels. As a result, a projected image does not become darker at the central portion of the display panel nor at the peripheral portion thereof in the projection type image display apparatus such as the active matrix type liquid crystal display apparatus.

A practical application of the present invention will now be described. Such a case will be described that the present invention is applied to a liquid crystal display panel employed for a pocket type liquid crystal color TV ,,. (the apparatus type number 3C-EI, 3E-J1, for example), which is put in the market by the applicant of the present invention as the liquid crystal display panel. The size of a screen of this liquid crystal display panel is 45.6 mm high by 61.8 mm wide. The pixel pitch P_0 is 190. μm in the vertical direction and 161 μm in the horizontal direction, the thickness t of the substrate is 1.1 mm, and the refractive index n of the substrate is 1.5. A focal length of tho projection lens is 200 mm, and L is approximately 200 mm.

The microlens array is manufactured by a method of obtaining a refractive index profile type lens by selective ion diffusion (Electronics Letters Vol. 17 No. 13 p. 452 (1981)). In this method, a glass plate is dipped in molten salt. A kind of metal ion, such as alkaline ions, are exchanged between the glass plate and the molten salt through a mask provided on the glass plate. As a result, the glass plate is obtained which has refractive index profile corresponding to a mask pattern.

The pitch of the microlens array *2a* at the side facing the light source is determined to be 190.7 μm in the vertical direction and 161.6 μm in the horizontal direction according to the equation (1). The pitch of the microlens array *2b* at the side facing to the projection lens is determined to be 189.3 μm in the vertical direction and 160.4 μm in the horizontal direction according to the equation (2). Correction of the pitches is not carried out for comparison, and a microlens array having the same pitch as the pixel pitch is also manufactured. Each microlens has a diameter of 150 μm and a focal length of 720 μm (=t/n) in the atmosphere.

Such a microlens array is employed for a projection type color liquid crystal display apparatus.

Only the central portion of the screen is effectively used for projection in the one in which the pitch correction of the microlens array is not carried out. The reason for this will be described as follows. That is, the light from the condenser lens 4 does not enter at the right angle to the liquid crystal display panel 1 but at a certain angle θ in the end portions of the display panel 1.

In this case, the angle θ is expressed as follows.

$$\begin{aligned}\tan\theta &= \{(\text{the width of the display panel})/2\}/L \\ &= \{(61.8)/2\}/200 \\ &= 0.1545\end{aligned}$$

In the case of no pitch correction of the microlens array, the light, which passes through the center of the microlenses at the side facing the light source and is then directed to the center of the projection lens, passes (t/n) x tan θ=113 μm apart from the center of the pixels. This deviation is larger than half the pixel pitch, so that it extends to the adjacent pixel. Furthermore, this light passes 226 μm apart from the center of the microlenses at the side facing the projection lens. This deviation is larger than one pixel pitch of the microlens array, and thus does not reach the projection lens.

Meanwhile, in the case of correcting the pitch of the microlens array according to the present invention, the light from the light source can effectively be utilized in even the peripheral portion of the projected image. Therefore, distribution of luminance becomes uniform over the entire screen, resulting in enhanced visibility.

In the above described embodiment, since the condenser lens 4 is provided at the side of the liquid crystal display panel facing the light source, the pitch of the microlens array at the light source side is made larger than the pixel pitch. On the other hand, if the condenser lens 4 is provided at the projection lens side, the pixel pitch is made larger than the pitch of the microlens array. No change can be seen in the capacity of light convergence in either case of facing a convex surface of the microlens array toward the display panel or away from it. However, the distance t varies, which is between the plane surface on which the pixels of the display panel are arranged and the surface on which the microlens array is provided. Therefore, the pitch and focal length of the microlens array need be varied in accordance with the variation of the distance t.

The present invention can also achieve the same effect when applied to a cylindrical lens (a semicylindrical lens or a lenticular lens) as it is applied to the spherical lens array as described above.

When the pitch of the pixels of the display panel in the width direction differs from that if the height direction, a microlens array in which boundaries of each microlens are partially fused may be used. In this case, an area to receive light can be increased. An example of such a lens is shown in FIG. 8.

The description of the present invention has been given with respect to the case of employing the microlens array formed by the method of obtaining the refractive index profile type lens through the selective ion

diffusion. As a matter of course, the present invention is also applicable to a microlens array formed by another method.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

What is claimed is:

1. A projection type image display apparatus in which light from a light source is projected through a projection lens onto a non-emissive display portion, and an image of the display portion is then projected onto a predetermined projection surface,

the display portion comprising:

a display panel, including a substrate of a refractive index n, on which a plurality of pixels are arranged in a matrix, separated from each other by a predetermined first pitch P_0; and

first microlens array, provided between the display panel and the light source, the first microlens array including a plurality of microlenses separated from each other by a predetermined second pitch P_1 and arranged in positions corresponding to the plurality of pixels on the display panel,

said first pitch P_0 and said second pitch P_1 being of different values and

satisfying the equation,

$P_1 = P_0 \cdot \{1 + t/(n+L)\}$, wherein t equals the distance between the display panel and the first microlens array and L equals the distance between the projection lens and the display panel.

2. A projection type image display apparatus according to claim 1, further comprising:

a second microlens array, provided between the display panel and the projection surface, the second microlens array including a plurality of microlenses arranged in positions corresponding to the plurality of pixels on the display panel.

3. A projection type image display apparatus according to claim 2, wherein

said plurality of microlenses of said second microlens array are separated from each other by a predetermined third pitch P_2, and wherein

said third pitch P_2 is smaller in value than said first pitch P_0.

4. A projection type image display apparatus according to claim 3, wherein

said plurality of pixels are arranged on a first plane surface on said display panel;

said plurality of microlenses on said first microlens array are provided on a second plane surface;

said plurality of microlenses of said second microlens array are provided on a third plane surface;

wherein a distance between said first plane surface and either of said second and third plane surfaces is t, and

pitch P_2 of said array satisfies the following expression,

$$P_2 = P_0 \ \{1 - t/(n \cdot L)\}.$$

5. A projection type image display apparatus according to claim 4, wherein

said plurality of pixels are formed in rows of a first direction and in rows of a second direction perpendicular to said first direction;

said plurality of microlenses of said first and second microlens arrays are provided in said first direction and in said second direction;

said plurality of microlenses formed in said second direction are integrated; and

said first and second microlens arrays include cylindrical lenses separated from each other by the predetermined second pitch P_1 in said first direction.

6. A projection type image display apparatus according to claim 5, wherein

said cylindrical lenses include semicylindrical lenses.

7. A projection type image display apparatus according to any one of claims 1 and 2, further comprising:

at least one condenser lens the light source and the display panel, for focusing light from the light source onto the predetermined projection surface, wherein the

first pitch P_1 is smaller in value than the second pitch P_1.

8. An image display device comprising:

display panel on which a plurality of pixels are arranged in a matrix, separated from each other by a predetermined first pitch;

first microlens array, provided between said display panel and a light source, including a plurality of microlenses separated from each other by a predetermined second pitch and arranged in positions corresponding to the plurality of pixels on the display panel; and

second microlens array, provided between said display panel and an image display surface, including a plurality of microlenses separated from each other by a predetermined third pitch and arranged in positions corresponding to the plurality of pixels on the display panel,

said predetermined first, second, and third pitch each being of a different value.

9. The image display device of claim 8 wherein,

said first pitch is larger in value than said third pitch.

10. The image display device of claim 8 wherein,

said second pitch is larger in value than said first pitch.

11. The image display device of claim 10 wherein,

said first pitch is larger in value than said third pitch.

12. A projection type image display apparatus in which light from a light source is projected through a projection lens onto a non-emissive display portion, and an image of the display portion is then projected onto a predetermined projection surface,

said display portion comprising:

a display panel on which a plurality of pixels are arranged in a matrix, separated from each other by a predetermined first pitch; and

first microlens array, provided between the display panel and the light source, and including a plurality of microlenses separated from each other by a predetermined second pitch and arranged in positions corresponding to the plurality of pixels on the display panel,

said predetermined first pitch being smaller in value than said predetermined second pitch.

13. A projection type image display apparatus according to claim 12, further comprising:

second microlens array, provided between the display panel and the predetermined projection surface, and including a plurality of microlenses arranged in positions corresponding to the plurality of pixels on the display panel.

14. A projection type image display apparatus according to claim 13, wherein

said plurality of microlenses of said second microlens array are separated from each other by a predetermined third pitch, and

said third pitch is smaller in value than said first pitch.

15. A projection type image display apparatus according to claim 14, wherien

said plurality of pixels are arranged on a first plane surface on said display panel;

said plurality of microlenses on said first microlens array are provided on a second plane surface;

said plurality of microlenses of said second microlens array are provided on a third plane surface;

wherein a distance between said first plane surface and either of said second and third plane surfaces is t,

a refractive index of a substrate of the display panel is n,

a distance between the display panel and the projection lens is L,

said first pitch is P_0, said second pitch is P_1, and said third pitch is P_2, and

pitches P_1 and P_2 of said first and second microlens arrays are selected to satisfy the following expressions:

$$P_1 = P_0 \cdot \{1 + t/(n \cdot L)\}$$

$$P_2 = P_0 \cdot \{1 - t/(n \cdot L)\}$$

16. A projection type image display apparatus according to claim 15, wherein

said plurality of pixels are formed in rows of a first direction and in rows of a second direction perpendicular to said first direction;

said plurality of microlenses of said first and second microlens arrays are provided in said first direction and in said second direction;

said plurality of microlenses formed in said second direction are integrated; and

said first and second microlens arrays include cylindrical lenses separated from each other by the predetermined second pitch in said first direction.

17. A projection type image display apparatus according to claim 16, wherien

said cylindrical lenses include semicylindrical lenses.

18. A projection type image display apparatus according to any one of claims 12 and 13, further comprising:

condenser lens, provided between the light source and the display panel, for focusing light from the light source onto the predetermined projection surface.

* * * * *

EXHIBIT I

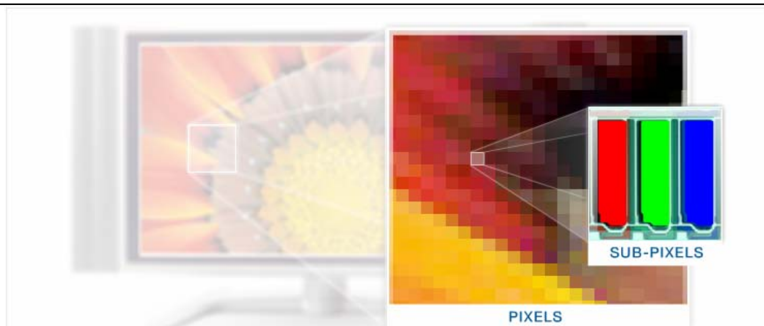
Excerpts from 3M's Optics 101 Tutorial

The title of each table herein corresponds to one of the chapter titles of the 3M tutorial. All images in the left column are excerpted from the full animated audio/visual version,

http://solutions.3m.com/wps/portal/3M/en_US/Vikuiti1/BrandProducts/secondary/optics101/.

All passages in the right column are quoted from the text that appears when a user clicks on the "INFO" button found in the lower-right corner of the tutorial. This text does not in all instances correspond to the audio track, which at times provides additional information to the written text. 3M's website is copyrighted ("© 3M 2008. All Rights Reserved.").

Excerpts from 3M's Optics 101 Tutorial

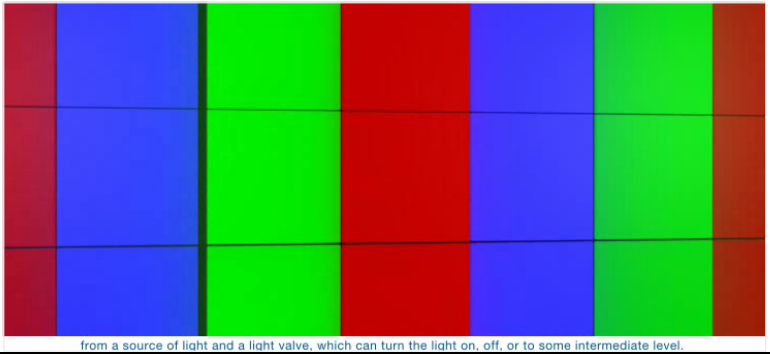
<table>
<tr><th colspan="2">3M's Chapter Entitled, Creating Electronic Images</th></tr>
<tr><td>
The images in any electronic display are made up of millions of tiny pixels, the smallest distinct element in an image.</td>
<td rowspan="2">The images in any electronic display are made up of millions of tiny pixels, the smallest distinct element in an image. Pixels in a color display are in turn made up of subpixels—red, green, and blue—which, when all added together at different levels of intensity can form nearly any color. When individually controlled and viewed from afar, the individual pixels and subpixels combine to form the images we see in electronic displays.</td></tr>
<tr><td>

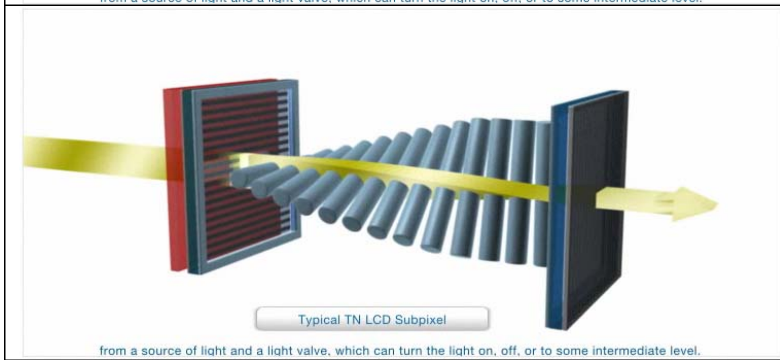
Pixels in a color display are in turn made up of subpixels—red, green, and blue—which, when all added together at</td></tr>
<tr><td>

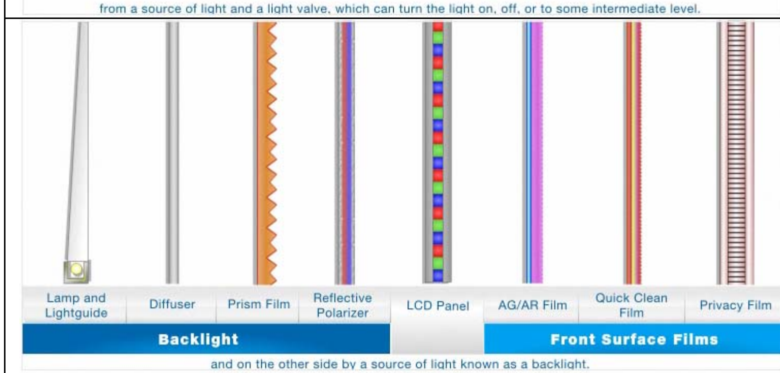
LCD TVs, calculators and digital watches.</td>
<td>An LCD, or liquid crystal display, is a commonly used electronic display found in a variety of electronic devices, including cell phones, laptop computers, computer monitors, LCD TVs, calculators and digital watches.</td></tr>
</table>

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD







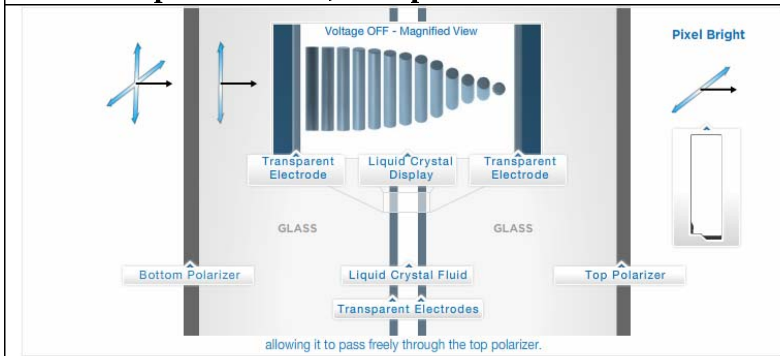
Each individual pixel in a black and white LCD and each subpixel in a color display are created from a source of light and a light valve, which can turn the light on, off, or to some intermediate level. In an LCD, millions of light valves form the display panel, while a backlight and various display enhancement films create the illumination.

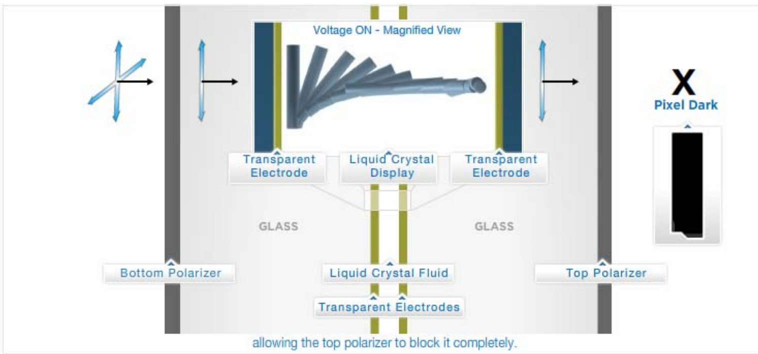
A cross-section of an LCD reveals its elements. The LCD panel is at the center of the display, which is where the liquid crystal itself is located. Transparent electrodes patterned on each pane of glass encompass the liquid crystal. The orientation of the liquid crystal can be changed in subtle ways by applying a voltage to the electrodes in order to change the level of illumination displayed in each sub-pixel.

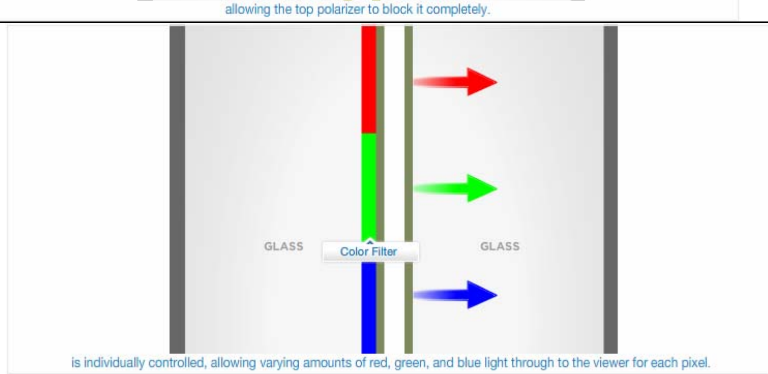
The panel is sandwiched on one side by various front surface films that enhance the display properties and on the other side by a source of light known as a backlight.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > LCD Panel Overview



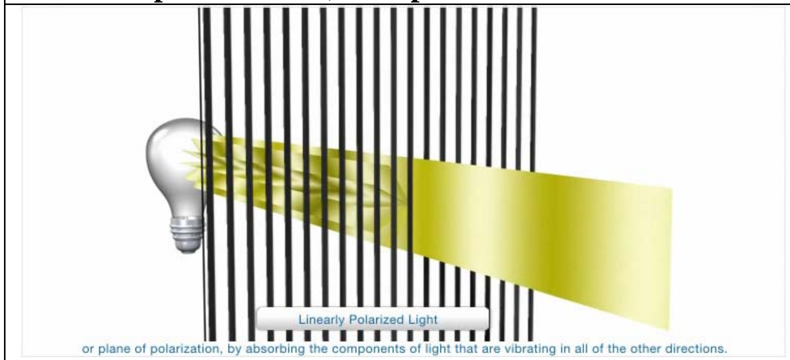




The LCD panel is the essential component in a display that controls the amount of light reaching the viewer. Light passes through a bottom polarizer that orients the light to a single state of polarization by absorbing over 50% of the incoming unpolarized light .The polarized light then passes through the liquid crystal layer. The orientation of the liquid crystal can be controlled by applying a voltage to the transparent electrodes on the glass encompassing it. The liquid crystal's degree of orientation controls to what degree it will rotate the incoming polarized light with a typical TN LCD. When there is no voltage applied to the electrodes, the liquid crystal is naturally oriented to rotate the light 90 degrees allowing it to pass freely through the top polarizer. However, if a voltage is applied, the liquid crystal aligns to the electric field and does not rotate the light, allowing the top polarizer to block it completely. By applying an intermediate voltage, the liquid crystal can be partially oriented to partially rotate the incoming light, creating shades of grey.

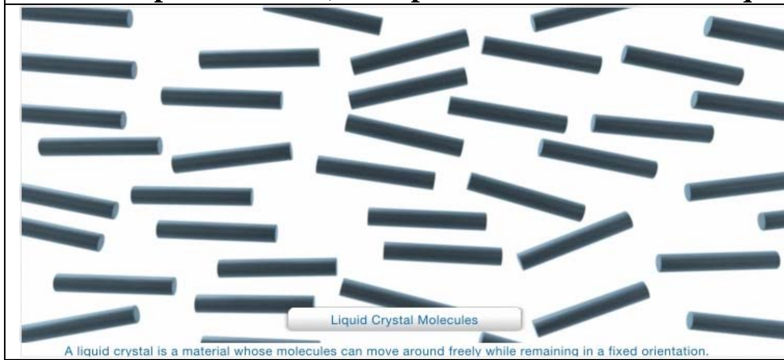
Adding a color filter to the LCD panel creates color displays. In a color LCD, each red, green and blue subpixel is individually controlled, allowing varying amounts of red, green, and blue light through to the viewer for each pixel.

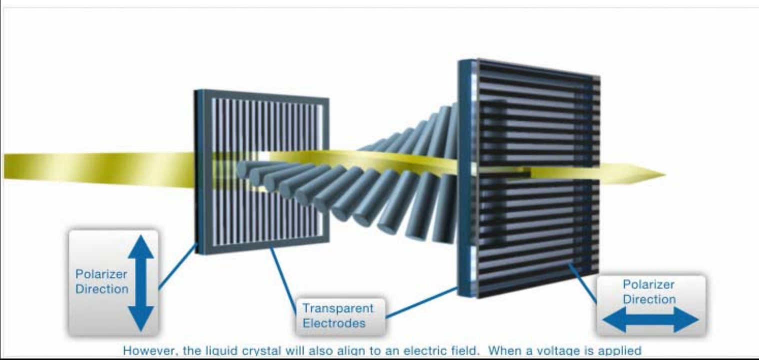
Excerpts from 3M's Optics 101 Tutorial

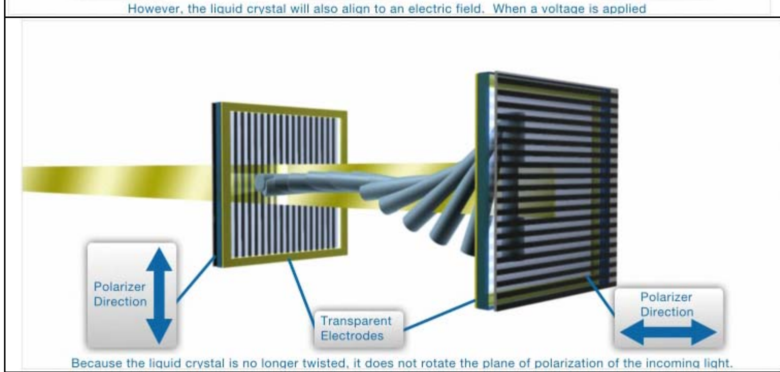
3M's Chapter Entitled, Components of an LCD > Polarizer Overview	
	When light travels, it vibrates in every direction. A linear polarizer restricts this vibration of light to a single direction, or plane of polarization, by absorbing the components of light that are vibrating in all of the other directions. This is critical to how an LCD works because a liquid crystal must have light vibrating in only one direction in order to act as a light valve. This is called linearly polarized light. If your laptop computer or LCD monitor lacked even one of its two polarizers, you would be staring at a blank, white screen. There are several types of polarizers, each of which is constructed in a different way for different applications.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > Liquid Crystal Overview







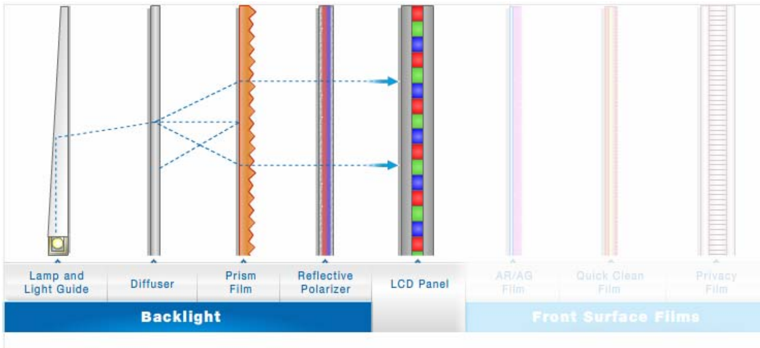
A liquid crystal is a material whose molecules can move around freely while remaining in a fixed orientation.

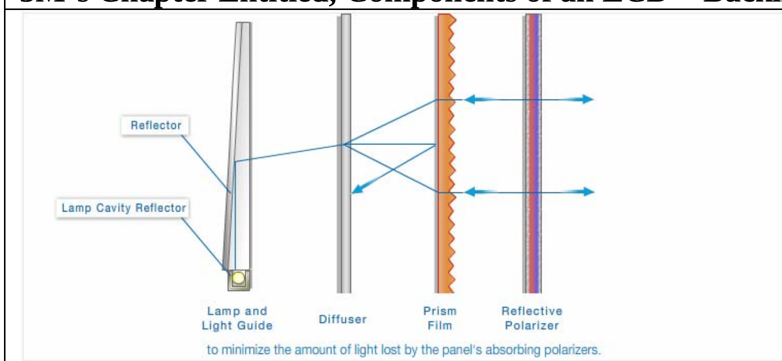
Certain types of liquid crystals are particularly useful in electronics displays because of their particular physical, optical and electrical properties.

The liquid crystal's physical properties will cause it to align itself to an alignment film on the inside of each piece of panel glass.

Because the alignment film on one side of the panel is not oriented in the same direction as the film on the other side, the liquid crystal is forced to twist through the thickness of the display panel to match the orientation of the films on both sides. It is this twist that controls the liquid crystal's optical properties, allowing it to rotate the incoming polarized light from one plane of polarization to an orthogonal plane of polarization. However, the liquid crystal will also align to an electric field. When a voltage is applied to the transparent electrodes on each side of the panel, the liquid crystal loses its twist, aligning instead with the electric field. Because the liquid crystal is no longer twisted, it does not rotate the plane of polarization of the incoming light. Different kinds of liquid crystal displays use different liquid crystal architectures and orientations.

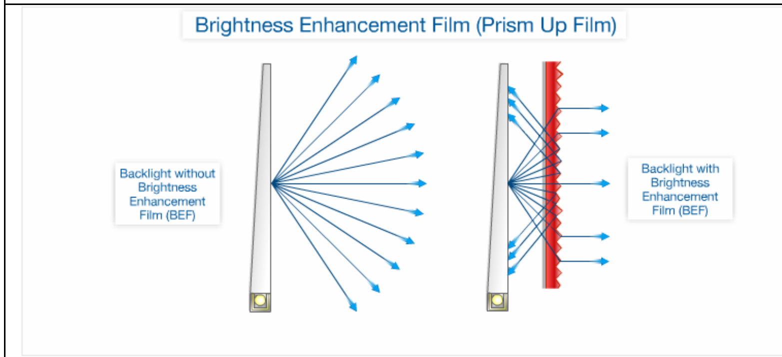
Excerpts from 3M's Optics 101 Tutorial

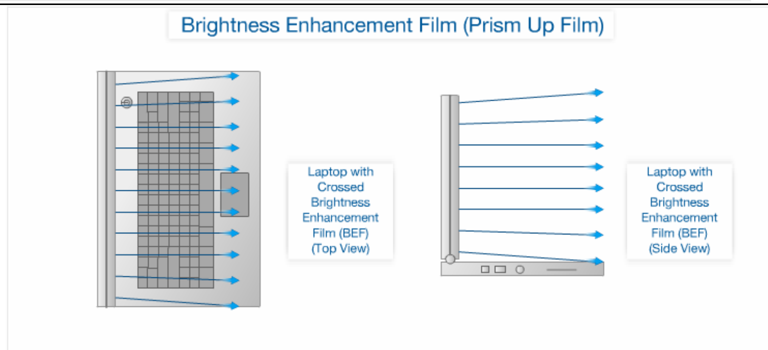
3M's Chapter Entitled, Components of an LCD > Backlight Overview	
	Light in an LCD originates from the backlight. The light is produced by a lamp which is typically a miniature version of a fluorescent tube or CCFL (cold cathode fluorescent lamp). The light enters a lightguide that distributes the light evenly across the back of the LCD panel. Diffusers are placed between the light guide and the backside of the LCD panel to further distribute the light uniformly across the display. Lastly, display enhancement films are typically placed between the diffuser and the LCD panel to better optimize the light coming from the backlight. The display enhancement films enable a higher percentage of the light to reach the viewer, rather than being absorbed by the bottom polarizer or exiting the display at undesirable angles.

3M's Chapter Entitled, Components of an LCD > Backlight Overview > Display Enhancement Films	
	Display enhancement films take the uniformly distributed light from the light guide and optimize its angular direction and polarization to make the LCD display appear brighter. Lamp cavity reflectors increase the light entering the light guide. Reflectors increase the light reflected from the rear of the backlight unit. Diffusers uniformly distribute the light. Prism films (and certain types of diffusers) optimize the angle of light exiting the display such that most of it is directed toward the display viewer. And lastly, reflective polarizers optimize the light's state of polarization to minimize the amount of light lost by the panel's absorbing polarizers.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > Backlight Overview > Display Enhancement Films > Brightness Enhancement Films (BEF)

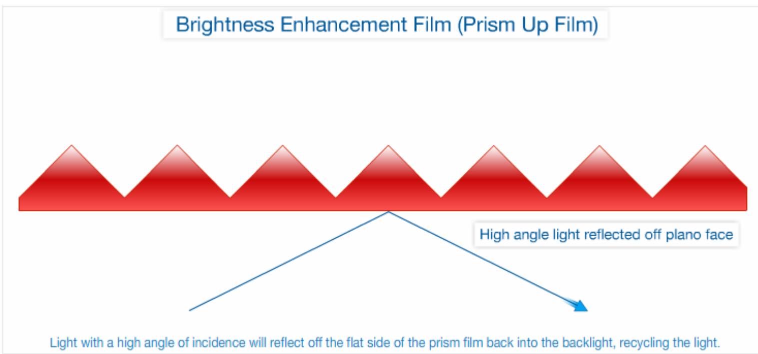


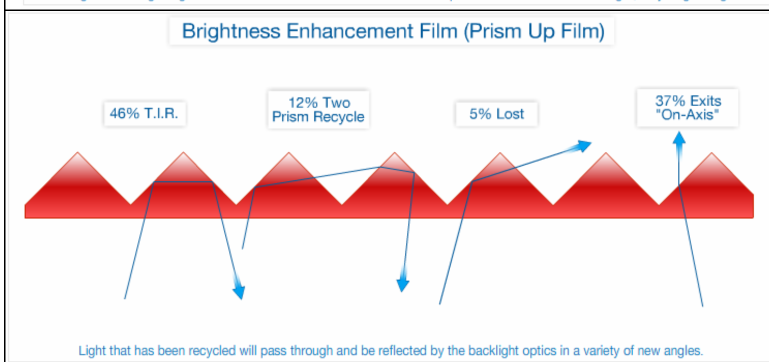


Prism brightness enhancement films, or BEF for short, manage the angle of light emitted from the backlight to direct more usable light to the viewer. Without BEF films, light would exit an LCD at angles outside the typical viewing range, much of it going to waste. A single piece of BEF can be used in LCD TVs to take the light that would be wasted on the ceiling and floor and redirects it to the viewer. In a laptop computer or cell phone, where only one person usually views the display at a time, two pieces of BEF, at crossed prism directions, are used to capture light otherwise wasted in the wide horizontal and vertical viewing directions. In notebooks and handheld devices the net effect is to provide brighter displays that require less power, significantly increasing battery life. In highly diffuse backlights, a single piece of BEF can increase brightness by approximately 60%, while two pieces of BEF with prisms crossed to one another can increase brightness by approximately 120%

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > Backlight Overview > Display Enhancement Films > Brightness Enhancement Films (BEF) > BEF Functions

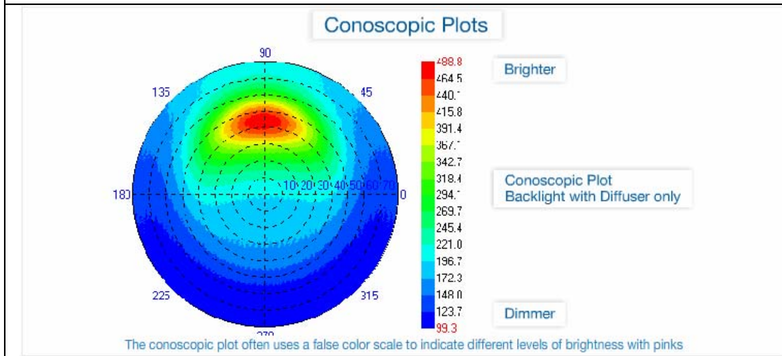


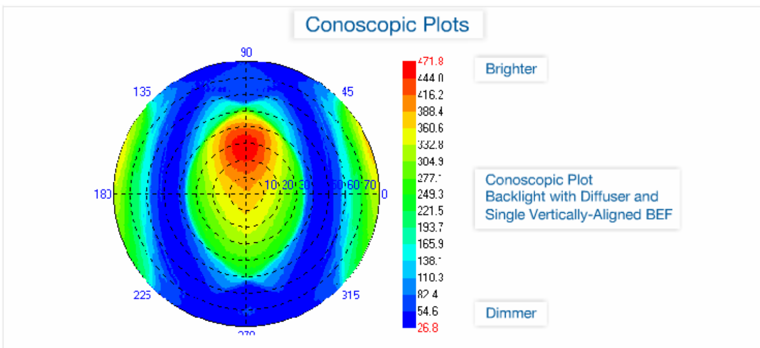


A prism brightness enhancement film has a single flat or "plano" side and an opposite side with microscopic prisms that run parallel to one another for the entire length of the film. As light exits the light guide or diffuser it travels in many directions. Light with a high angle of incidence will reflect off the flat side of the prism film back into the backlight, recycling the light. The remaining light enters the film and is refracted at the air / film interface according to Snell's law. If light enters BEF at all angles, 46% of the light that enters the film will be recycled back to the backlight via total internal reflection. 12% of this light will be reflected off the first prism face, refracted by the second prism face and then will enter an adjacent prism where it will be reflected back in the backlight (recycled). 5% of the light will also be reflected off one prism face and refracted by the other, but will miss any adjacent prisms and will not be recycled. Lastly, 37% of the light entering the prism film will be refracted by a single prism face in a direction perpendicular to the display face ("on-axis"), toward the viewer. Light that has been recycled will pass through and be reflected by the backlight optics in a variety of new angles. Light returning to the prism BEF will then exit the prism film to the viewer, or be recycled once again.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > Backlight Overview > Display Enhancement Films > Brightness Enhancement Films (BEF) > BEF Effects





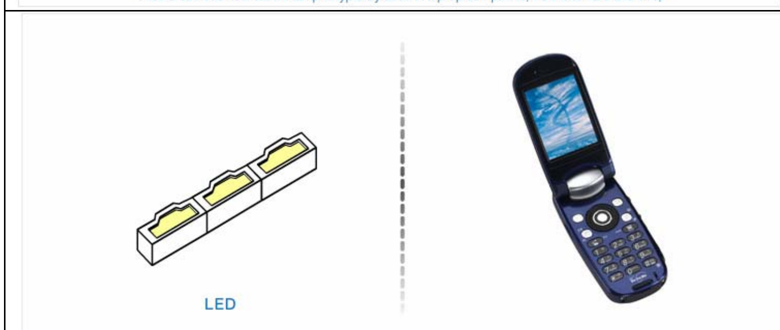
The utility of a brightness enhancement film can be measured in terms of the gain in brightness it delivers to the liquid crystal display as a function of viewing angle. Conoscopes measure brightness as a function of exit angle from a display and produce a polar plot this output. The conoscopic plot often uses a false color scale to indicate different levels of brightness, with reds and oranges brighter than greens and blues. The conoscopic plot for a wedge lightguide plus a diffuser shows most of the light spreading widely along horizontal angles, and traveling at high (grazing) vertical angles. Adding a single piece of vertically aligned BEF to the stack collapses the horizontal angle spread, but does not appreciably affect the vertical exit angle. Adding a second piece of BEF aligned horizontally will alter the vertical component of the exit angle so that the majority of the light exits the display "on-axis"; that is to say, traveling along the normal to the screen. By taking a cross section of this plot, one can see the brightness as a function of viewing angle in either the vertical or horizontal angle directions.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Components of an LCD > Backlight Overview > Sources of Light


The choice of a light source by the display designer is critical in balancing the requirements of color gamut,

A cold cathode flourescent lamp is typically used in laptop computers, LCD Monitors and TVs,



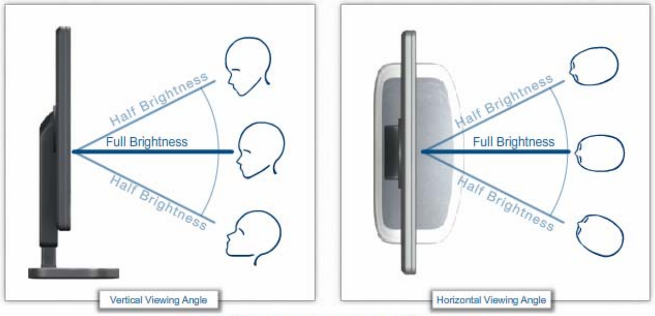
LEDs are the primary light source in hand-held devices such as cell phones and PDAs.

All LCDs require a source of light to illuminate the LCD panel. The choice of a light source by the display designer is critical in balancing the requirements of color gamut, power consumption, heat generation, size, and cost. Each light source has a different spectral output that constrains the color gamut of the integrated display and each light source lends itself to different applications. Using sunlight or ambient room light works well for watches and cell phones with simple transflective displays. A cold cathode fluorescent lamp is typically used in laptop computers, LCD Monitors and TVs, while the powerful light of an arc lamp is used in most LCD projectors. LEDs are the primary light source in hand-held devices such as cell phones and PDAs.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Performance Characteristics	
	There are many types of LCDs, differing in a number of performance characteristics. Viewing angle relates to how well you can see a display image when looked at from the side of a display (referred to as off axis viewing). Brightness relates to the amount of light the display emits. Contrast ratio refers to the ratio of brightness between white and black areas in an image. Color gamut concerns the range of colors that can be seen in the display. Uniformity describes the consistency of color and brightness across display images. Moiré is a phenomenon where undesirable visual patterns appear, interfering with the quality of the image.

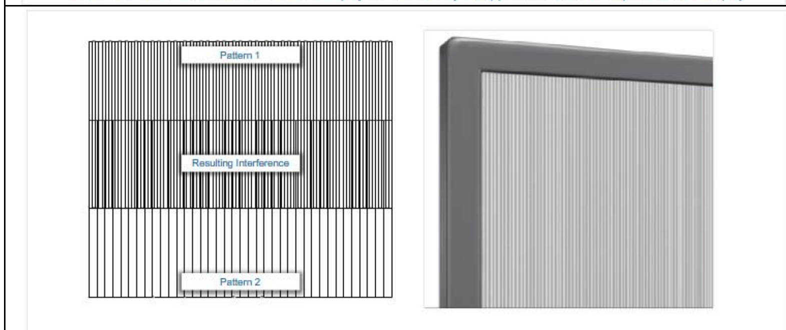
Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Performance Characteristics > Viewing Angle	
 one half of the brightness as seen by looking head on.	Viewing angle is a property of LCD performance that indicates how the quality of an image deteriorates when viewed from a position other than directly in front of the display. It is typically measured as the angle at which the brightness of the display drops to one half of the brightness as seen by looking head-on. Standard TN displays show significant image deterioration at oblique angles, particularly when the display is viewed from above or below. The display looses its brightness and colors are significantly distorted. One way to improve the viewing angle of an LCD is to add a compensation film to correct for the asymmetry in the display system. The various types of LCDs (TN, IPS, VA, MVA, ASV, and OCB) utilize varying degrees of compensation films to improve image quality at all angles.
 particularily when the display is viewed from above or below.	

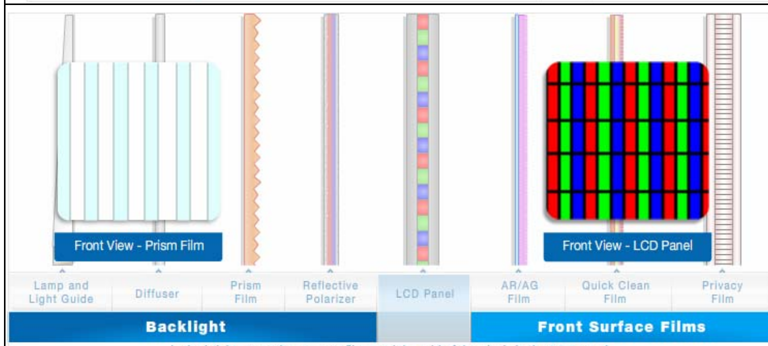
Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Performance Characteristics > Moiré Explained

Moiré is an undesirable visual defect in an LCD display characterized by the appearance of band-like patterns in the display.



In general, moiré can result from the interference of two or more periodic patterns.



in the brightness enhancement films and the grid of the pixels in the LCD panel.

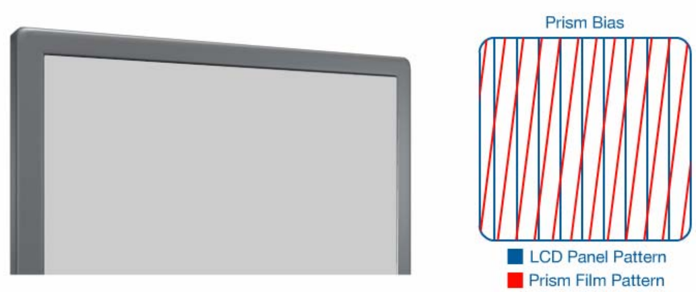
Moirs [sic] is an undesirable visual defect in an LCD display characterized by the appearance of band-like patterns in the display. In general, moirian [sic] result from the interference of two or more periodic patterns. In the case of an LCD, the periodic patterns are provided by evenly spaced prisms in the brightness enhancement films and the grid of the pixels in the LCD panel.

Moiran [sic] be a function of viewing angle, since the periodic lines caused by the prism film vary in contrast with the viewing angle. Typically the moirattern [sic] is most apparent when the viewing the LCD off axis.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Performance Characteristics > Moiré Solutions

There are various solutions to reduce pixel moiré in an LCD.



in relation to the LCD panel, to reduce the moiré fringe pitch

There are various solutions to eliminate pixel moirn [sic] an LCD. First, a diffuser sheet or cover sheet can be placed between the prism film and the LCD panel. The diffusion acts to soften the periodic pattern of the prism film, lessening the interaction with the pixel in the panel. Unfortunately, a cover sheet adds additional thickness and additional cost while lowering the brightness of the display. A second solution is to bias the angle between the prism film in relation to the LCD panel. For small bias angles this solution may not significantly affect brightness, but adds cost due to custom converting requirements of the prism film. The pitch of the prism film can also be tuned to the pixel pitch of the LCD panel to eliminate the interference. This solution does not affect brightness and no specialized converting is required. Moirand [sic] isibility can also be reduced by breaking up prism regularity, although this can sometimes cause new moir atterns [sic] to emerge.

Excerpts from 3M's Optics 101 Tutorial

3M's Chapter Entitled, Performance Characteristics > Moiré Solutions [Continued]	
 Additionally, moiré can be reduced by tuning the pitch of the	
 Adjusting the bias angle and prism structure tends to maintain display brightness compared to the use of a diffuser sheet.	

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